APPENDIX A

HYDRAULIC DESIGN

SAINT PAUL, ALASKA

APPENDIX A

HYDRAULIC DESIGN

Harbor Improvements - St. Paul, Alaska

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<u>SUPPLEMENT TO APPENDIX</u>: Miscellaneous Paper ERDC/CHL-01
Design for Small Boat Harbor Improvements and Tidal Flushing at St. Paul Harbor, St. Paul Alaska, February 2001

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HARBOR IMPROVEMENTS - ST. PAUL, ALASKA
APPENDIX A: HYDRAULIC DESIGN

1. INTRODUCTION

1.1 Appendix Purpose

This hydraulic design appendix describes the technical aspects of the St. Paul Harbor Improvements Project. It provides the basis for determining the Federal interest in the construction of a small boat harbor. The small boat harbor is located in the Bering Sea within the confines of protection afforded by the 1996 Federal Harbor Improvement Plan, which forms the basis for the deeper-draft harbors. A location and vicinity map are shown in Figure A-1. Three model studies were performed and form the basis for design of the small boat harbor, which is located within the embayment formed by the deeper-draft harbor breakwaters.

The first modeling effort was a three-dimensional harbor model used to check the relative differences in harbor wave action, currents, and sedimentation. The model compares the conditions before and after the modifications to the deeper - draft harbor now authorized for construction. Modifications included deepening of the entrance channel, construction of a maneuvering basin, construction of a spending beach, construction of a sediment management area, and construction of energy dissipation berms to reduce wave activity on the existing West breakwater. Details of most of those authorized improvements are contained in the *Harbor Improvements Interim Feasibility Report*, Saint Paul Alaska, August 1966.

The second modeling effort also used the three dimensional model. The purpose of the second effort was to study wave induced currents and flushing within the Salt Lagoon. Incidental to that purpose was a study to determine the impacts of a small boat basin situated in the approximate location of the new proposed basin on waves, currents, sedimentation and tidal flushing. The study concluded that improving the Salt Lagoon channel, constructing a sediment management area and constructing a detached breakwater between the east inlet and the proposed harbor would enhance water quality in the lagoon and allow the development of a small boat harbor. The results of that modeling effort can be found in Bottin and Acuff's *Study for Flushing of Salt Lagoon and Small Boat Harbor Improvements at St. Paul Harbor*, St. Paul Alaska, August 1997.

The third modeling effort also used the previously mentioned three-dimensional model to:

- Define the potential for harbor surge,
- Define small boat harbor wave activity,
- Ensure Salt Lagoon flushing with the proposed harbor in place,
- Maximize the exchange of water in the small boat harbor,
- Test ultimate development in other areas of the embayment,

- Test ice circulation patterns,
- Locate the interior detached breakwater to best enhance circulation in the small boat harbor and Salt Lagoon, and
- Ensure that the decrease in elevation of the spending beach did not have a major impact on waves or circulation. The reduction in elevation was requested by environmental interests to reduce seal haul-out potential.

NOTE: The report from the third modeling effort is appended hereto and is entitled Miscellaneous Paper ERDC/CHL-01, Design of Small Boat Harbor Improvements and Tidal Flushing at St. Paul Harbor, St. Paul Island, Alaska.

1.1 Project Purpose

The following objectives were identified for the small boat basin at St. Paul Harbor before beginning this engineering analysis.

1. Develop a harbor facility for a day fishing fleet within the general confines of the existing St. Paul Harbor embayment without conflicting in a significant manner with other land use and other development plans.

2. Design and construct improvements to provide a safe and efficient harbor, which satisfies the above objectives in an environmentally and economically sound manner.

Five harbor designs were analyzed in varying degrees to develop the economic and environmental data to assure that the correct harbor was selected. Those configurations were a 30-, 60- and 90-vessel harbor at the 12-foot depth and 60-vessel harbors at the 8- and 10-foot depths.

1.2 Background

The Alaska District Corps of Engineers initially examined small boat harbor development on a preliminary basis. The City of St. Paul contracted for the development of an Information Report in 1996 to define the Federal interest in a small boat Harbor at St. Paul. That report identified a Federal interest in the development. On the basis of that report a small boat harbor was authorized by congress. Additional work was required to assure economic and engineering viability. This report results from that requirement.

2. CLIMATOLOGY, METEOROLOGY, AND HYDROLOGY

2.1 Climatology

St. Paul is the northernmost and largest of the Pribilof Islands. It is located at latitude 57°10' N and longitude 170°10' W in the central southeast Bering Sea, as illustrated in Figure A-1. The region has a maritime climate, with considerable cloudiness, heavy fog, high humidity, and limited daily temperature fluctuations. The humidity remains uniformly high from May to late September. There is almost continuous low cloudiness and occasional heavy fog during the summer months.

Maritime influence in the Pribilof Islands keeps seasonal temperatures mild and daily variations to a minimum. The average difference between maximum and minimum daily temperatures for the year is only slightly above 7° F, with the greatest monthly variation being slightly less than 12° F in March. Summer temperatures are low, with the highest recorded temperature being 64° F in August of both 1936 and 1941. Extreme high temperatures in summer are usually in the mid-fifties. Although record low temperatures fall well below 0° F, such cold days are rare. On the average, temperatures fall below zero only 5 days each winter. Table A-6 lists meteorological data collected by the U.S. Department of Commerce, National Oceanographic and Atmospheric Administration (NOAA).

The island area has periods of high wind throughout the year. Frequent storms occur from October to April, often accompanied by gale-force winds to produce blizzard conditions. The average sea surface temperature in the Bering Sea surrounding the Pribilof Islands varies from 32.5° F in February to 47° F in August.

2.2 Tides and Water Levels

Tide levels at Village Cove on St. Paul Island, referenced to MLLW, are shown in Table A-1. Extreme high tide levels result from the combination of astronomic tides and rises in local water levels due to atmospheric pressure and wave conditions.

TABLE A-1: St. Paul Tide Levels (feet)

Highest Tide (estimated)	+6.0
Mean Higher High Water (MHHW)	+3.2
Mean High Water (MHW)	+3.0
Mean Sea Level (MSL)	+2.0
Mean Low Water (MLW)	+1.0
Mean Lower Low Water (MLLW)	0.0
Lowest Tide (estimated)	-2.5

Source: NOAA Tide Tables, 1980.

The design still water level (SWL), or highest tide, has likely been underestimated in previous studies. Our analysis after modeling and measuring seiche conditions indicates that a still water level of 6 feet above Mean Lower Low Water (+6' MLLW) is probably correct. Harbor seiche, or wave beat, accounts for varying levels of higher water. The model indicates that long-period surges (about 2-minute oscillations) further increase those levels by as much as four feet.

Still water levels have been previously estimated by analyzing videotapes of 1994 storms. Several reference points of known elevation in the video were used as datums to estimate the SWL during these storm events. An elevation of +7.0' MLLW was estimated based on these observations, which represents a 2-foot increase from the SWL used for design purposes in the 1988 St. Paul GDM. Further analyses of the videotapes and survey information using reference points on the *Unisea* (a fish processing vessel moored in the harbor) indicated that the water surface in the harbor during the November 1994 storm was approximately +5.4' MLLW. The St. Paul harbormaster indicated that the highest water surface level observed in the harbor has been approximately +7.4' MLLW. A review of the tapes indicates that part of the maximum elevations observed might have came from a long-period harbor surge. An examination of model results indicates that as much as 4 feet of surge elevation with a period between 110 seconds and 140 seconds probably occurs in the harbor at several locations. The design high water level when surges are accounted for is approximately 9 feet MLLW.

2.3 Currents

The *U.S. Coast Pilot No. 9* and *Tidal Current Tables, Pacific Coast of North America and Asia* (NOAA 1986) indicate that currents near Village Cove are primarily tidal and are typically 1 to 2 knots, occasionally increasing to 3 knots when augmented by strong winds. The strongest nearby currents (to 3 knots) are encountered southeast of Village Cove between Reef Point and Otter Island. Currents within the localized area of the harbor are however dominated by storm surge and wave setup. Model studies of the harbor without planned improvements indicated that currents of up to 8 fps more than double the magnitude of currents associated with tides. Figure A-2 shows the current patterns and current prototype magnitudes that can be expected during extreme storm periods with proposed improvements in place. Those currents are similar to maximums encountered without the proposed small boat harbor, as shown in Figure A-3. Figure A-4 shows currents under average wave and tide conditions with the harbor in place. The boundaries for the major currents within the harbor area without interior harbor modifications appear to be Boulder Spit on the east with a flow separation and an eddy forming the boundary on the southeast corner. The currents then rejoin the shoreline near the historic Western terminus of the Salt Lagoon channel (the small boat harbor rubble breakwater). They then proceed to the docked shoreline on the south, and thence to the western main breakwater. The flow separation and eddy in the historic migration path of the Salt Lagoon entrance is a phenomenon that has probably existed for centuries, and its implications on sediment size in the eddy pocket may be profound, as transport of the boulder-size material found on Boulder Spit should be limited to the eddy area. It is suspected that sediments in the eddy area will have very few large boulders to at least a depth of -12’ MLLW.

2.4 Wind Data

Wind data and return point period information for the St. Paul area were collected from the *Climatic Atlas* (Bureau of Land Management 1977) and *Extreme Wind Predictions for First Order Weather Stations in Alaska* (Alaska Climatic Center 1984). The maximum sustained wind speed in the 1984 Alaska Climatic Center report is approximately 51 miles per hour for a 1-year return period. Sustained winds are winds averaged over a period of 1 minute. Figure A-5 extracted from the St. Paul Feasibility Report displays the extreme wind speed predictions in miles per hour. Wind speeds in excess of 40 mph of several days duration occur and create water level differential around the Island. Monthly and annual wind roses (Figures A-6.1 through A-6.13) indicate that navigation within the harbor could be difficult when arriving or leaving, and that channels will on occasion need to accommodate vessel drift caused by high wind. The wind roses also indicate that mixing of interior harbor waters will occur and that there will be mass transport of water caused by wind setup.

2.5 Ice Conditions

The icepack in the Northern Bering Sea occasionally moves south and surrounds the island during periods of prolonged north and northeast winds between January and May. NOAA charts warn mariners against the possibility of entrapment in Village Cove. An icebreaker has never been necessary for access to the island. Interior harbor currents at most times will allow ice to bypass the small boat harbor; however, winds can drive float ice into the harbor. Ice conditions may therefore interfere with the proposed day fishery mooring facilities during the months of January through May. Vessel removal for short periods may be a requirement in some years. The photo in Figure A-7 is taken from the island towards the northeast and shows sea ice in the vicinity of the small boat harbor.

3. WAVES

3.1 Wave Exposure

The existing deep-draft harbor in Village Cove is in direct alignment with deep-water waves approaching between the west-northwest and southwest sectors, with an exposure window bounded approximately by azimuths between 210° and 294° relative to true north, as shown in Figure A-8. Deep-water waves approaching from the south and southeast sectors are partially sheltered by St. George Island and Otter Island, and would diffract around Reef Point before impinging on the project site. southerly and southeasterly deep-water waves therefore undergo considerable energy reduction before arriving at the project site. Village Cove is in the lee of St. Paul Island for waves approaching clockwise from northwest through southeast. Waves in the Bering Sea are extremely large, and around the shallower waters of St. Paul Island their heights are depth-limited during numerous events each year. Maximum wave height to be expected near the entrance to the present harbor is 27 feet.

3.2 Deep-Water Waves

Deep-water waves cover an extreme range of periods. Based on buoy data, those periods can extend to 26 seconds. Harbor seiche waves and the resulting surf beat due were of concern after currents and vessel motions were examined in the previous model. Thus harbor seiche was identified as one aspect of modeling. Data from the NDBC.EMDA at latitude 57.0 N Longitude 177.7 W are included as Tables A-7.1 through A-7.3. The data are a compilation of the annual and monthly records accumulated from 9/85 through 12/93 and show the percent frequency of significant wave heights versus dominant wave period in seconds on the basis of percent frequency of occurrence. That data set can be supplemented prior to construction by a recent 15-year wave hindcast for the months of June through November at latitude 57.0 N, Longitude 189.9 W, which is adjacent to St. Paul Island. That information is not yet in a format suitable for publication but is an indicator of summer wave conditions.

BUOY: 46035 POR: 9/1985 - 12/1993 (66899 RECORDS) LATITUDE 57.0 N LONGITUDE 177.7W

1 - MONTHLY AND ANNUAL FREQUENCY AND CUMULATIVE PERCENT FREQUENCY (10THS)

ELEMENT: SIGNIFICANT WAVE HEIGHT (METERS) POR: 9/1985 - 12/1993 (66899 RECORDS, 95.8% HAVE ELEMENT)

	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF
13.0																			1	#			6	#	7	#
12.5	1	#																					3	999	4	999
12.0																			2	999			1	999	3	999
11.5	5	999																	2	999			2	998	9	999
11.0	9	999															1	#	4	999	2	#	3	998	19	999
10.5	11	997															4	999	2	999	2	999	7	998	26	999
10.0	13	995	5	#	1	#											3	999	3	998	4	999	10	996	39	999
9.5	17	993	8	999	2	999	4	#									2	998	9	998	9	999	12	995	63	998
9.0	29	990	6	997	9	999	4	999									4	998	6	996	14	997	17	993	89	997
8.5	45	985	17	996	29	998	6	999											11	995	29	995	29	990	166	996
8.0	40	977	33	993	20	993	16	997									6	997	14	994	48	990	39	985	216	993
7.5	55	970	31	987	34	989	18	995	1	#							8	996	18	991	62	982	64	979	291	990
7.0	76	960	47	980	30	983	31	991	3	999							18	995	42	989	89	972	82	969	418	985
6.5	127	946	89	971	88	978	42	986	9	999					2	#	20	991	65	982	111	957	146	956	699	979
6.0	192	924	146	954	132	963	50	978	14	998					6	999	31	987	75	972	185	939	206	932	1037	968
5.5	270	889	176	925	170	939	68	969	12	995					24	998	47	981	130	960	275	909	307	899	1479	952
5.0	388	841	232	891	238	909	112	957	24	993	9	#	1	#	13	993	86	972	235	939	322	863	426	849	2086	929
4.5	447	772	346	846	335	868	146	937	49	988	31	998	5	999	51	990	135	956	320	902	401	810	528	781	2794	896
4.0	518	692	412	778	448	809	194	910	120	979	56	991	28	999	78	978	240	929	460	851	608	744	651	696	3813	853
3.5	585	600	567	697	481	730	240	875	209	956	72	979	65	992	150	959	329	883	720	778	864	644	843	591	5125	793
3.0	664	495	576	586	726	645	493	832	351	916	112	963	99	977	268	925	567	819	782	664	947	502	904	455	6489	713
2.5	724	377	872	474	890	518	772	743	595	849	256	939	228	953	492	862	781	710	997	540	833	346	926	309	8366	612
2.0	696	248	820	303	883	361	1015	603	1020	736	448	883	484	900	730	747	989	559	1061	382	785	209	734	160	9665	481
1.5	540	123	495	143	830	206	1134	420	1259	542	1108	786	1028	786	1229	577	1158	368	968	213	393	80	212	42	10354	331
1.0	151	27	211	46	320	60	993	215	1303	303	1838	545	1575	543	1097	291	699	144	369	60	94	16	45	8	8695	169
.5	1	*	25	5	23	4	195	35	292	56	669	145	732	172	152	35	44	9	7	1	1	*	2	*	2143	33
MEAN		3.6		3.2		3.0		2.3		1.8		1.4		1.3		1.8		2.3		2.9		3.5		3.7		2.7
S.D.		1.8		1.5		1.5		1.4		.9		.8		.7		.9		1.2		1.4		1.5		1.6		1.6
TOTAL		5604		5114		5689		5533		5261		4599		4245		4292		5172		6303		6078		6205		64095
MAX		12.4		10.2		10.1		9.5		7.6		5.2		4.8		6.5		10.8		12.9		10.8		13.1		13.1
DATE		90011916		92020413		87032106		87040216		92051110		88061219		90072117		88083106		87092204		89101004		92111301		87121516		87121516
MIN		.7		.4		.6		.4		.4		.4		.4		.4		.5		.6		.5		.7		.4
DATE		93012006		86022801		86031406		91040915		87052810		93061418		86071002		87082821		86092114		88100405		88111520		88121213		93061418

(* < 0.05% , # = 100.0%)

Table A-7.1

BUOY: 46035 POR: 9/1985 - 12/1993 (66899 RECORDS) LATITUDE 57.0N LONGITUDE 177.7W

1 - MONTHLY AND ANNUAL FREQUENCY AND CUMULATIVE PERCENT FREQUENCY (10THS)

ELEMENT: AVERAGE WAVE PERIOD (SECONDS) POR: 9/1985 - 12/1993 (66899 RECORDS, 95.8% HAVE ELEMENT)

	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF
13																							1	#	1	#
12	1	#			5	#											2	#	5	#	3	#	21	999	37	999
11	53	999	10	#	25	999	8	#									11	999	17	999	45	999	59	996	228	999
10	296	990	117	998	111	995	51	999	7	#							31	997	118	997	248	992	218	987	1197	996
9	608	938	467	975	510	975	318	989	56	999			2	#	29	#	200	991	412	978	767	951	903	952	4272	977
8	1373	829	1102	884	1237	886	638	932	333	988	95	#	36	999	175	993	586	953	1290	912	1505	825	1859	806	10229	911
7	1796	584	1615	668	1436	668	1071	817	1168	925	485	979	389	991	1064	952	1557	840	2237	708	2050	577	2073	507	16941	751
6	1230	264	1355	353	1740	416	1884	623	1914	703	1796	874	1613	899	1996	705	1882	538	1695	353	1248	240	888	173	19241	487
5	237	44	417	88	582	110	1344	282	1594	339	1966	483	1918	519	967	240	864	175	508	84	205	35	179	29	10781	186
4	10	2	31	6	43	8	219	40	188	36	255	56	282	68	60	14	39	8	21	3	7	1	4	1	1159	18
3									1	*	2	*	5	1	1	*									9	*
MEAN		7.3		7.0		6.9		6.3		6.0		5.6		5.5		6.0		6.5		6.9		7.3		7.5		6.6
S.D.		1.2		1.2		1.2		1.3		1.0		.8		.7		.8		1.1		1.1		1.2		1.2		1.3
TOTAL		5604		5114		5689		5533		5261		4599		4245		4292		5172		6303		6078		6205		64095
MAX		11.6		10.9		12.0		11.0		10.2		8.3		8.7		9.2		11.6		11.9		11.8		12.7		12.7
DATE		90011916		89020504		93031613		87040219		88051100		88060811		90070121		88083106		92091023		89101007		92111307		87121519		87121519
MIN		3.8		3.8		3.9		3.5		3.4		3.4		3.4		3.4		4.0		3.8		4.2		4.3		3.4
DATE		93012009		86022803		92032820		92041921		92053123		92060104		92073101		87082909		92090212		91102421		85110223		89123003		92073101

(* < 0.05% , # = 100.0%)

Table A-7.2

BUOY: 46035 POR: 9/1985 - 12/1993 (66899 RECORDS) LATITUDE 57.0N LONGITUDE 177.7W

1 - MONTHLY AND ANNUAL FREQUENCY AND CUMULATIVE PERCENT FREQUENCY (10THS)

ELEMENT: DOMINANT WAVE PERIOD (SECONDS) POR: 9/1985 - 12/1993 (66899 RECORDS, 95.8% HAVE ELEMENT)

	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF	F	CPF
25.0	1	#																	2	#			1	#	4	#
20.0	4	999	2	#	13	#			3	#							3	#	7	999	3	#	7	999	42	999
16.7	65	999	37	999	68	998	27	#	27	999	5	#	4	#	23	#	37	999	34	999	91	999	102	999	520	999
14.3	318	988	254	992	316	986	166	995	73	994	24	999	20	999	119	995	116	992	174	993	268	985	299	982	2147	991
12.5	768	931	594	943	661	930	480	965	132	980	47	994	52	994	238	967	146	970	541	966	793	940	930	934	5382	958
11.0	995	794	836	827	907	814	646	878	445	955	132	983	133	982	201	911	436	942	812	880	1224	810	1399	784	8166	874
10.0	1111	616	805	663	767	655	684	762	671	871	274	955	211	951	333	865	814	857	1331	751	1278	609	1353	559	9632	746
9.0	857	418	691	506	655	520	626	638	585	743	416	895	339	901	632	787	938	700	1184	540	906	398	967	341	8796	596
8.0	923	265	1060	371	1158	405	1090	525	1184	632	1164	805	1007	821	1203	640	1434	519	1354	352	1081	249	800	185	13458	459
7.0	350	100	502	163	684	201	806	328	1012	407	1112	552	1068	584	770	360	687	241	570	137	284	71	206	56	8051	249
6.0	164	38	232	65	341	81	658	182	767	215	979	310	886	332	580	180	404	108	226	46	111	25	105	23	5453	123
5.0	39	9	71	20	104	21	278	63	306	69	368	97	407	123	163	45	127	30	53	10	27	6	35	6	1978	38
4.0	9	2	25	6	15	3	68	13	52	11	73	17	105	28	22	7	29	6	13	2	11	2	1	*	423	7
3.0			5	1			4	1	4	1	5	1	12	3	8	2	1	*							39	1
MEAN		10.1		9.6		9.6		8.8		8.2		7.4		7.3		8.3		8.7		9.5		10.1		10.4		9.1
S.D.		2.2		2.3		2.5		2.4		2.1		1.7		1.8		2.2		2.0		2.0		2.1		2.0		2.3
TOTAL		5604		5114		5689		5533		5261		4599		4244		4292		5172		6301		6077		6205		64091
MAX		25.0		20.0		20.0		16.7		20.0		16.7		16.7		16.7		20.0		25.0		20.0		25.0		25.0
DATE		92010707		92021321		93031610		93042812		89050516		93061505		89071404		93081307		92091009		86101105		93110619		93121622		93121622
MIN		3.7		3.0		4.0		3.2		3.1		3.2		3.0		2.8		3.4		3.8		3.7		4.2		2.8
DATE		93012010		86022803		90033121		92041920		92053123		89061802		92072407		87082907		86092114		88100408		85110300		90120900		87082907

(* < 0.05% , # = 100.0%)

Table A-7.3

3.3 Waves Inside the Deep-Draft Harbor

3.3.1 Short-period waves

Previous model studies indicate the source of wave activity in the harbor and (within a reasonable error range) the magnitude of the energy. Short-period wave heights in the present harbor are greatly modified by the breakwaters and spending beaches. Waves are attenuated to less than three feet by existing protection. Wave energy enters through both the east and west entrances, with the dominant energy entering through the west entrance (the deep-draft navigation channel). Shallow water conditions in the eastern end are effective in reducing short wave energy.

3.3.2 Long-period waves

Long-period waves from 35-second to 170-second periods exist in the harbor and are a combination of the external surf beat phenomenon and interior seiche waves. Heights associated with these waves are all less than three feet under extreme storm conditions and much less during lower energy periods. The longest period waves (> 110 seconds) oscillate on the east west axis of the harbor on a dominant period between 110 seconds and 140 seconds. The slow oscillation and low current velocities in the small boat harbor associated with the seiche allow harbor mooring development in an east-West direction as depicted in the drawing for the 60-vessel harbor. The maximum strengths of the oscillating currents are 1 fps or less, as shown in Figure A-9. Mooring pile heights must exceed the maximum surge level by several feet and vessel moorings must be secured to offset the stresses developed during the seiches. The surges create navigation concerns in the entrance channel, as there are negative oscillations of nearly 1.5 feet at MLLW. Oscillations are severely dampened as the tides become negative because of the shallow zone between the Spending Beach and east shore. Offshore winds during extreme negative tides will eliminate both the potential to oscillate and the short period waves in the harbor. Cross-channel currents also occur during events in which vessels would leave the harbor. During the most severe storms, waves external to the deep-draft harbor will prevent movement to sea, and thus the currents at that time are not a major concern. Under more modest conditions design channel widths are adequate to assure safe passage. Current velocities also require that erosion protection be added between the spending beach and the interior detached breakwater.

4. EXISTING HARBOR

4.1 General Description and Background

The present St. Paul Harbor was completed in 1990 and consists of a main breakwater 1,800 feet long, a detached breakwater 970 feet long, and space for 900 feet of docks on the lee side of the main breakwater. Currently the city has 200 feet of concrete caisson dock and 100 feet of steel pile dock. Tanadgusix (TDX), the local Native corporation, has also constructed a 300-foot dock. A plan view of the harbor layout is shown in Figure A-10.1. The drawing shows both existing and planned facilities, in addition to the proposed 60-vessel small boat harbor. Figure A-10.2 shows the 30-vessel harbor layout. Figure A-11 shows the 60-vessel harbor with wave gauge locations shown.

4.2 Improvements Underway

Three offshore reefs shown in Figure A-10.1 are under construction. The reefs are each 1250 feet long and will extend above the sea floor to an elevation of -12' MLLW. The reefs' alignments are parallel to the existing breakwater. The reefs' center- lines follow a -28' MLLW contour offshore of the existing breakwater. The purpose of the reefs is to attenuate wave energy on the main breakwater.

4.3 Authorized Improvements to be Constructed Prior to or Concurrently with the Small Boat Harbor

A dredged entrance channel at -30' MLLW with an additional 2 feet for advanced maintenance. A 415-ft by 830-ft maneuvering basin at -29' MLLW. A spending beach on the lee side of the detached breakwater. A realigned Salt Lagoon entrance channel, a sediment management area immediately inside of east entrance, and a detached breakwater located between the new lagoon entrance and the remainder of the harbor complex to direct flows within the total harbor complex. These elements are mitigation measures to restore circulation and water quality to the Salt Lagoon.

4.4 Future Improvement Possibilities

Deepening of the harbor for commercial use on the west side of the proposed small boat harbor rubble breakwater.

5. MODEL STUDY

5.1 General

The same model was used as in previous design efforts. The model reproduced approximately 2,865 m (9,400 ft) of the St. Paul Island shoreline. This produces an extent from Tolsti Point easterly and then southerly to a point south of the existing breakwater trunk. It also reproduces the existing harbor and underwater topography in the Bering Sea to an offshore depth of 12.2 m (40 ft) with a sloping transition to the wave generation pit elevation of -30.5 m (-100 ft). A small connecting channel to the Salt Lagoon (located east of the harbor) also was included in the model as well as the tidal prism of the Salt Lagoon. The total area reproduced in the model was approximately 605 sq m (6,500 sq ft), representing about 6 sq km (2.3 sq mi) in the prototype. Vertical control for model construction was based on mean lower low water (MLLW), and horizontal control was referenced to a local prototype grid system. A general view of the model is shown in the model report appended to this document.

5.2 Analysis of Model Data

Relative merits of the various plans were evaluated by:

1. Comparison of short-period wave heights and long-period wave heights (seiches) at selected locations in the model.
2. Comparison of wave-induced current patterns and magnitudes.
3. Comparison of tidal flows.
4. Visual observations.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s) was computed using data from each gauge location. All wave heights then were adjusted by application of Keulegan's equation to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel. The model data can then be corrected and converted to their prototype equivalents.

Wave data were filtered, and both short-period storm wave conditions as well as long-period wave conditions were presented at the various gauge locations. In addition, wave-induced current velocities obtained in the model were the maximum that occurred during the wave spectra (usually occurring after a series of large waves in the wave signal and at long-period nodal points).

5.3 Previous Experiments

Twelve study plans were evaluated during the initial portion of this investigation (Bottin 1996), and 15 plans were evaluated during the first reactivation of the model (Bottin and Acuff 1997). Therefore, plan numbering for this experimental series began with Plan number 28.

5.4 New Experiments

Three principal conditions were studied in the model: A 60-vessel harbor, a 30-vessel harbor, and expansion of the dredged area in front of the TDX Docks. The 60-vessel harbor was first examined with varying levels of protection and entrance hydraulic efficiency to obtain desirable flushing. Gyre circulation in this model indicated that further expansion either to the south or east would result in some difficulty in obtaining adequate flushing. The 90-vessel harbor was not examined in the model as both land use and flushing conditions would make satisfactory development difficult. The 60-vessel harbor configurations were then checked to see if a 30-vessel harbor could be accommodated. When performance of the system was confirmed a separate study was conducted to see if further deep-draft harbor expansion could be accommodated.

The new study was initiated with a model consisting of a 9.8-m-deep (32-ft-deep) draft entrance channel, an 8.8-m-deep (29-ft-deep) maneuvering area, a 3-m-deep (10-ft-deep) sediment trap, a 0.9-m-deep (3-ft-deep) connecting channel from the harbor to the Salt Lagoon, a wave-dissipating spending beach inside the harbor [el 0.0 m (0.0 ft) with a +1.2 m (+4 ft) berm along its perimeter], and an interior detached breakwater. These conditions were developed in previous studies and are authorized for construction and remained in the model for all experiments with the exception that the interior detached breakwater position and orientation were modified. Proposed improvement plans for this experimental series consisted of dredging a new small boat channel and boat basin as well as installation of a shore-connected breakwater and adjustment of the interior detached breakwater. The interior detached breakwater is used to manage water quality in the Salt Lagoon and interior harbor. Modifications also were made to the existing shoreline and depths in the existing harbor. Wave heights and wave-induced current patterns and magnitudes were obtained for variations in the harbor that consisted of changes in shoreline configurations, depths and/or structure lengths and alignments. Experiments of tidal flushing were conducted for changes in the orientation of the interior detached breakwater and depths in the harbor. Study plans that consisted of shoreline and depth changes in the harbor were expeditiously constructed in the model using gravel to determine optimum layouts. A total of 12 plans were tested in this series. Descriptions and layouts of the small boat harbor improvement plans are presented in the model study report appended to this document. The conditions measured in plan 37 (the optimized 60-vessel harbor) are shown in Figures A-2 and A-9, and Tables A-8.1 and A-8.2. These conditions were used to design various aspects of the harbor. Figure A-3 shows current patterns and maximum surge velocities without the small boat harbor in place.

Table A-8.1: Short-Period Wave Heights for Plan 37

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (s)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.1	0.6	0.3	0.7	0.5	0.3	0.2	0.3	0.2	0.2	0.6
16	19	4.2	1.4	0.6	1.6	1.0	0.8	0.4	0.4	0.6	0.4	1.5
20	14	3.5	1.2	0.5	1.5	1.0	0.7	0.4	0.4	0.4	0.4	1.1
25	10	3.1	0.9	0.4	1.5	0.9	0.6	0.2	0.3	0.4	0.3	0.9
swl = +7.0 ft												
10	10	3.7	1.0	0.3	0.8	0.6	0.3	0.3	0.3	0.5	0.3	0.8
16	19	5.4	1.8	0.7	1.8	1.5	0.9	0.6	0.7	0.8	0.6	2.3
20	14	4.8	1.7	0.6	1.8	1.4	0.8	0.6	0.6	0.8	0.6	2.0
25	10	4.5	1.5	0.5	2.0	1.2	0.6	0.5	0.5	0.7	0.5	1.7

Table A-8.2: Long-Period Wave Heights for Plan 37

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (s)	Height (ft)	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.5	0.9	2.1	1.3	1.0	1.0	1.2	1.2	0.8	0.9	1.2
16	19	4.7	1.9	3.4	2.7	2.0	1.9	2.2	2.2	1.6	2.0	2.3
20	14	4.1	1.8	3.0	2.4	2.0	1.7	1.9	2.0	1.3	1.6	2.0
25	10	3.5	1.3	2.6	2.3	1.6	1.4	1.9	1.8	1.8	1.6	1.4
swl = +7.0 ft												
10	10	3.7	1.2	2.2	1.3	1.3	1.1	1.3	1.4	0.9	1.0	1.2
16	19	5.8	2.4	4.0	3.1	2.7	1.8	2.4	2.4	1.9	2.1	3.5
20	14	5.3	2.3	4.0	2.9	2.5	1.9	2.4	2.7	1.8	2.0	2.8
25	10	4.8	1.9	2.9	2.7	1.9	1.5	2.0	2.1	1.5	1.7	2.3

5.5 Wave Height Experiments

Wave height experiments were conducted for the initial and most promising improvement plans for the waves from 8 to 25 seconds. Experiments involving some proposed plans, however, were limited to the most critical wave conditions (i.e., 16-sec, 19-ft waves). Wave gauge locations are shown in the model study

5.6 Wave-Induced Current Patterns and Magnitudes

Wave-induced current patterns and magnitudes were obtained for selected improvement plans for various wave conditions. These experiments were conducted by timing the progress of a dye tracer relative to a known distance on the model surface at selected locations in the model.

5.7 Tidal Flow Experiments

Tidal flow experiments were conducted for selected improvement plans to determine flushing action throughout the harbor. Tidal current patterns and magnitudes were obtained with a dye tracer similarly to those obtained for wave-induced currents.

5.8 Experimental Results

In analyzing results, the relative merits of various improvement plans were based on measured wave heights, wave-induced current patterns and magnitudes, and tidal flow currents. Model wave heights (significant wave heights or H_s) were tabulated to show measured values at selected locations. Wave-induced and tidal current patterns and magnitudes are shown in the figures in the report as previously cited.

5.9 Conclusions

Based on results of the coastal model investigation reported herein, it is concluded that:

1. Preliminary experiments indicated that all improvement plans would result in wave heights of less than 0.3 m (1.0 ft) in the small boat mooring area for short-period storm wave conditions.

3. Preliminary experiments indicated that the harbor would experience long-period (surge) conditions for all improvement plans. These surges are at their extremes at maximum tide conditions, exceeding 3 feet some places in the harbor at the extreme tide of 7+ feet. When water depths are decreased, the east entrance depths decrease the available energy. They are insignificant at the extreme minus tide condition and estimated at about 1.5 ft at the 0-MLLW tide condition.

3. Preliminary experiments indicated that the area between the wave-dissipating spending beach and the interior detached breakwater should be constructed to an elevation of -0.6 m (-2.0 ft) to reduce wave heights in the small boat harbor mooring areas. Excessive wave-induced currents in this area, however, indicated that the area should be hardened (capped with riprap) to prevent scour.

4. Preliminary experiments indicated that strong wave-induced currents in the interior channel might cause navigation difficulties for extreme storm wave events. Strong wave-induced currents along the area east of the shore-connected breakwater also may pose problems for vessels mooring in this vicinity. These current magnitudes also indicate that toe protection at the head of the structure may be required.

5. Preliminary experiments indicated that the angled interior detached breakwater would result in enhanced circulation and better distribution of flow in the small boat harbor basin for ebb tidal currents as opposed to the straight structure.

6. Preliminary experiments indicated that the -4.9-m-deep (-16-ft-deep) interior channel would result in enhanced wave-induced circulation and stronger eddies in the small boat basin as opposed to the -3.7-m-deep (-12-ft-deep) channel.

7. Experiments indicated that the 60-vessel plan configuration (Plan 37) would provide adequate wave and surge protection to the small boat harbor as well as adequate harbor circulation.

8. Experiments indicated that the 30-vessel plan configuration (Plan 38) will provide adequate wave and surge protection to the small boat harbor as well as adequate harbor circulation

9. Experiments indicated that a reduction of depths in the harbor to -6.7 m (-22 ft) west of the interior shore-connected breakwater (Plan 39) would have no negative impacts on wave and surge conditions or harbor circulation in the small boat harbor.

10. Experiments indicated that long-period surge conditions would occur in the harbor. Problems resulting from those conditions should be limited provided dock systems are properly oriented and vessels properly moored.

11. Experiments indicated that the 0.0-m (0.0-ft) elevation of the wave-dissipating spending beach (with the +1.2-m (+4.0-ft) berm along its perimeter) studied during this period will provide essentially the same level of protection from storm waves in the mooring area as the +3.7-m (+12.0-ft) elevation spending beach tested in earlier studies.

6. HARBOR DESIGN

6.1 General

Input parameters for harbor design were based on input from public meetings as far as harbor layout and basic criteria for dock facilities to maintain a given size and composition fleet. The physical controls for design were extracted from model studies, climatological data and common practice for harbor depths and channel dimensions. Previous sections identify most of this input data.

6.2 Design Vessel and Design Fleet

The 60-vessel harbor economic analysis was based upon the boat sizes presented in Table A-9. Other harbor sizes assumed a similar ratio of vessel sizes. The design vessel length was estimated at 60 ft. The average beam was estimated to be in excess of 30 percent of the length, and 22 feet was used. The loaded draft used for the major part of the harbor was 8.0 feet and in the shallower section it was assumed the drafts were 4.5 feet or less.

Table A-9: Distribution by Vessel Size Class in the 60-Vessel Harbor

Size Class	Number of Vessels in Moorage
0 to 26 feet	28 [1]
>26 to 39 feet	17
>39 to 55 feet	13
>55 feet	22
Local fleet total [2]	80
Local fleet w/o hand-launched skiffs	60

[1] The allocated harvest justifies 8 vessels based on the income threshold. We have included an estimated 20 local skiffs in this class. All are tailored or carried and are anticipated to be users of the launch ramp.
[2] Includes hand-launched skiffs not kept in the harbor

6.3 Harbor and Channel Depth for Navigation

The harbor was designed to provide ingress and egress for vessels for all reasonable conditions. The entrance channel design depth was based on the following requirements:

- Vessel draft of 8 ft.
- Safety Clearance of 2 ft when long and short-period waves are present. This safety clearance was selected even though boulders may be present at dredged

depth. Movement of sand and boulders after construction is not expected and no dredging tolerance will be allowed during construction.

- Long-period oscillation at MLLW condition + or – 1.5 feet.
- Short-period oscillations at MLLW + or – 0.5 feet.

The combination of the above requirements resulted in an entrance and maneuvering channel depth of -12' MLLW. A minus tide was then selected, which would allow entrance and exit under all but the most extreme conditions of offshore winds if safety clearances were adequate. 2.5 MLLW tide elevation was selected, as it is an approximate 99% use condition. Depth requirements were based on the following assumptions:

- Long- and short-period waves were blocked by shallow water conditions at the east entrance and by offshore winds. Long- and short-period oscillations are 0 ft.
- The channel depth of 12 feet required at MLLW was found to be usable at the –2.5' MLLW tide with a safety clearance of 1.5 feet entailing either minor waiting or very minor risk therefore no economic analysis was undertaken to study the incremental costs and benefits of channel use between MLLW and –2.5 MLLW.
- Harbor depths in the mooring areas were selected at 1.5 feet below the lowest expected tide for the various vessels in the fleet.

6.4 Channel Depth Required for Flushing

The harbor was tested for its flushing characteristics using both a 3.2-foot tide and a 7-foot tide with the navigation channel at the -12' MLLW elevation. This was combined with the smallest persistent wave that would normally be encountered during the non-storm periods. Circulation within the harbor was developed under these conditions but the multiple gyre system was weaker than without project conditions. To improve gyre strength the hydraulic efficiency of the small boat basin entrance was improved by deepening by 4 feet to an elevation of -16' MLLW. Gyres were strengthened to the point that the mass transfer of water by this mechanism was similar to the without project conditions. Wind and wave setup in the harbor are other major mechanisms for mass transfer and mixing. These remain unchanged under with and without project conditions. Entrance channel depth required for water quality levels similar to existing conditions on the southeastern shoreline is -16' MLLW.

6.5 Entrance and Maneuvering Channel Width

The entrance channel was designed for two-way traffic under optimum conditions of wind and currents and was initially 5 vessel beams in width or 110 feet. The breakwater was extended and the channel reduced to 100 feet to preserve breakwater and spending beach integrity within the confines of the authorized channel depths. The 100-foot width allows 2-way traffic where vessel speeds are not constrained under most conditions. One-way traffic is possible under the more adverse wind and current conditions. The maneuvering channel was widened to 120 feet to account for the wind and current drift associated with constrained vessel speeds. Congestion-associated arrivals and departures from the docks also make additional maneuvering room beneficial.

6.6 Basis of Breakwater Design

The breakwater is designed in accordance with guidance given in the Corps of Engineers Shore Protection Manual. The design was then checked to see if the velocities caused by the harbor seiche at this location could control design.

- Maximum wave in the Harbor = 3 feet
- K_{rr} = 2.5 Non-breaking wave (Table 7-8 SPM)
- Hudson Formula:

  $\boldsymbol{W_{50} = wr \cdot H^3}$

  $K_{rr} \cdot (S-1)^3 \cot(o)$

  W_{50} = 50% size of rock gradation
  W_r = Unit weight of rock
  H_{zz} = Design wave height
  K_{rr} = Stability coefficient for grade rubble
  cot(o) = Cotangent of the slope

  - $W_{50} = 165 \cdot 9/2.5 \cdot (4.86) \cdot (1.5) = 600$ lbs.

The maximum size was selected as 2 tons. A well-graded mix without zoning is to be used in the construction as that size material makes up a high percentage of material that can be produced at both St. Paul and at St. George quarries. By using this mix a bedding layer will not be required. Rock sizes based on velocities encountered near the nose of the breakwater were established using the Corps of Engineers ChanlPro program for sizing rock on stream banks.

BREAKWATER VELOCITY CHECK

PROGRAM OUTPUT FOR A CHANNEL WITH A KNOWN LOCAL DEPTH-AVERAGED VELOCITY, BENDWAY

INPUT PARAMETERS

SPECIFIC WEIGHT OF STONE, PCF	165.0	
MINIMUM CENTER LINE BEND RADIUS, FT 200.0		
WATER SURFACE WIDTH, FT	200.0	
LOCAL FLOW DEPTH, FT	15.0	
CHANNEL SIDE SLOPE		1 VER: 1.5 HOR
LOCAL DEPTH AVG VELOCITY, FPS	8.00	
SIDE SLOPE CORRECTION FACTOR K1	.71	
CORRECTION FOR VELOCITY PROFILE IN BEND	1.22	

RIPRAP DESIGN SAFETY FACTOR 1.10

SELECTED STABLE GRADATIONS (ETL GRADATION)

LIMITS OF STONE WEIGHT (LB)
FOR PERCENT LIGHTER BY WEIGHT

100		50		15	
36	15	11	7	5	2
86	35	26	17	13	5

Wave activity dominates the design; therefore, 2 ton minus stone is to be used on the breakwater.

6.7 Wave Height in the Moorage Area

The desirable maximum wave heights in a small boat harbor are established by EM 1110-2-1615, "Hydraulic Design of Small Boat Harbors," which contains the following statements:

Purpose and Scope. This manual provides guidance for planning, layout and design of small boat harbor projects. These projects include boat basins, boat ramps, and channels. Small boats are classified as recreational craft, fishing boats, or other small commercial craft with lengths less than 100 feet. . . . Moorage areas need sufficient area to allow berthing piers and interior channels to accommodate the intended fleet. Anchorage areas must safely accommodate the intended fleet considering vessel movement when at anchor. Maximum allowable wave heights generally are limited to one foot in berthing and two feet in anchorage areas.

This manual guidance is in reference to short-period waves in the harbor. Guidance on long-period waves (seiches) indicates that considerable seiche sizes can be accommodated if vessels and docks are properly oriented and moorings account for the forces imposed by the seiche activity.

Some clarification of that guidance with respect to seiches is given in Special Report No. 2, *Small-Craft Harbors: Design, Construction and Operation*, U.S. Army Corps of Engineers (December 1974):

The normal criteria for acceptable wave actions are that the significant height of any wave episode not exceed about 2 to 4 feet in the entrance channel and 1 to 1.5 feet in the berthing areas, depending on the characteristics of the using craft. Generally, if waves can be attenuated to a height of about 1 foot in the berthing areas, their horizontal oscillations will not be troublesome, and any longer-period resonant effects will go unnoticed.

Based on model studies, short-period wave heights of less than 1 foot prevailed in the harbor under all test conditions (see APPENDED model study report). Long-period waves in the 110-second to 140-second range will, however, be present in the harbor. The southeastern corner of the harbor has the maximum vertical response in a seiche mode under these conditions. The seiche is oriented in an east to West direction and therefore boat moorages must be oriented in that direction to allow a vessel to ride with the seiche when moored. The harbor layout shown in the recommended plan responds to this orientation. Seiches in other harbors are managed by moorage orientation and close control of moorings. Harbor oscillation horizontal velocities are quite low, and mooring stresses should be easily accommodated. Velocities off the end of the breakwater and across the wave control zone between the spending beach and detached interior breakwater will require erosion protection. The dock lying adjacent to and east of the small boat harbor rubble breakwater will see vertical oscillations but has been set back from the end of the breakwater to avoid horizontal current velocities. Sponsor management of dock use and tie up will be required but curtailed use is only expected less than 10% of the time during the winter season based on wave information contained in this report.

6.8 Erosion Protection

The areas requiring erosion protection were determined from model studies**.** The zones that have high velocities are in the vicinity of the breakwater nose and the high insitu ground that supplies natural harbor wave protection. The high ground is that area between the spending beach and the interior detached breakwater. The -2' MLLW grade must be maintained at that location for wave protection and also retained for flushing control for the harbor, The area will be excavated so that erosion protection can be placed to the -2' MLLW elevation. The erosion protection was sized using ChanlPro.

PROGRAM OUTPUT FOR A CHANNEL WITH A KNOWN LOCAL DEPTH-AVERAGED VELOCITY, STRAIGHT REACH

INPUT PARAMETERS

SPECIFIC WEIGHT OF STONE, PCF	165.0	
LOCAL FLOW DEPTH, FT	12.0	
CHANNEL SIDE SLOPE,		1 VER: 3 HOR
LOCAL DEPTH AVG VELOCITY, FPS	8.00	
SIDE SLOPE CORRECTION FACTOR K1	.99	
CORRECTION FOR VELOCITY PROFILE IN BEND	1.00	
RIPRAP DESIGN SAFETY FACTOR	1.10	

SELECTED STABLE GRADATIONS (ETL GRADATION)

LIMITS OF STONE WEIGHT (LB)
FOR PERCENT LIGHTER BY WEIGHT

100		50		15	
36	15	11	7	5	2

A fifty-pound minus riprap was chosen with a two-foot layer thickness. The added thickness was selected in lieu of a gravel filter. A plus or minus tolerance of 6 inches is to be allowed over an area not exceeding 200 square feet to allow ease in placement. Insitu boulders need not be removed if they lie within this tolerance, and erosion protection can be continuous without sand pockets.

6.9 Interior Harbor Design

The orientation of moorings depicted on the drawings is critical to the harbor functioning satisfactorily during periods of seicheing. Other elements of the mooring docks, floating dock, boat ramp and boat haulout trailer have not received detailed design analysis but are in use at other harbors. Detailed design should be undertaken prior to installation of these facilities.

6.10 Future Harbor Dredging Modifications

Deepening in front of the TDX docks is a future possibility. The harbor lying west of the small boat harbor was examined to see the impacts on the small boat harbor, other portions of the harbor, and water quality. The area was modeled and the differences between conditions with existing topography and with deepening to -22' MLLW were examined and found to be minor. Harbor circulation is adequate to allow development and there was not an obvious environmental or technical reason to constrain future development. There are technical items that must be considered. The harbor seiche manifests itself in this segment of the harbor also. The surge is a gain oscillating on an east to west axis making mooring perpendicular to this direction difficult. Local desire to place a fixed dock parallel to the small boat harbor breakwater will need to take the seiche conditions under consideration. A more elaborate finger pier arrangement may be desirable.

7. RECOMMENDED PLAN

7.1 Description

The recommended small boat harbor consists of a federally developed entrance and maneuvering channel and a west breakwater. The entrance and maneuvering channels in the interior of the harbor are constructed to a depth of -12' MLLW to within 100 feet of the harbor breakwater. The entrance is initiated at the boundary of the turning basin and extends from that point to a position about 100 feet inside the harbor. The depth as required for flushing in this segment is -16' MLLW. At that position it transitions to a depth of -12' MLLW. The width of the entrance channel segment where vessel speed allows reasonable control is 100 feet with a depth of -12' MLLW. In the speed-restricted maneuvering channel the width increases to 120 feet at a 12-foot depth. The entrance channel narrows to 65 feet at the eastern segment of the harbor that is used by smaller craft in the fleet. The Federal breakwater is 445 feet in length and is constructed to an elevation of +10' MLLW. The breakwater elevation assumes an extreme tide of 6' MLLW plus a surge of 4 feet. Model results show that surges may exceed this value under certain circumstances. Those circumstances, however, are infrequent and added elevation is not deemed necessary. Breakwater construction is a randomly placed rubble mound with 1.5 on 1 side slopes. Erosion control is required in the areas shown between the spending beach and the interior detached breakwater and in the channel along the end of the harbor breakwater. The eastern end of the harbor is bounded by a circulation berm requested by environmental interests. The berm will control waters that might enter from the relic channel lying east of Grass Islands. The berm is built from the constructed +10' MLLW elevation in the services area to the Grass Islands. The berm is constructed to a top elevation of +10' MLLW and capped with filter and revetment. The revetment will be composed of the 12 inch minus boulders removed during excavation of the harbor.

7.2 Harbor Water Quality

Harbor water quality is dominated by the exchange of tide-generated flow through the harbor on its way to and from the Salt Lagoon combined with wave driven currents. The differential head between the western and eastern entrance to the deep-draft harbor created by minor wave activity creates an almost continuous flow through the deep-draft and small boat harbor. An added mechanism that creates both mixing and exchange is the high predominance of winds from the north. Other winds create mixing but the north winds create mass transport of water through the harbor. The Salt Lagoon surface is also more than three times that of the harbor and more than double the tidal prism. The impact of the Salt Lagoon is that when wind mixing occurs, the harbor waters are mostly exchanged in one tidal cycle. The winds eliminate the stagnation potential of the waters that are partially isolated from the Salt Lagoon effects. Circulation is generally good. The winds that assail this site will do an excellent job of mixing the water.

7.3 Salt Lagoon Water Quality

The Salt Lagoon water exchange is dominated by tides. Because of the small range in tidal elevation and length of basin, several tide cycles are required before all the water is exchanged. Mixing of water in the tidal lagoon should be good because waters are shallow and winds are frequent and strong enough to stir from top to bottom. Storm surge water elevations of up to three or four feet above normal tidal elevations cause supplemental exchange in the lagoon and periodically improve water quality. The shaping and deepening of the lagoon entrance channel will improve water exchange. The placement of the detached interior breakwater favors waters entering the lagoon directly from the ocean source rather than through the harbor complexes and should guarantee high-quality entrant waters. Those modifications will be undertaken concurrently with other authorized components of the deep-draft harbor. The combination of planned improvements minimizes the risk of degrading water quality through harbor activities and greatly enhances the system now in existence.

7.4 Sedimentation

Shoaling within the small boat harbor will be very limited as the deep-draft harbor entrance channel forms a trap at the western end of the system and the sediment management area forms a trap on the eastern end. Wind blown sands will however continue to contribute a small amount of sediment on the eastern boundary of the project.

Sediments in the harbor area are gap graded. The sediments consist of sands and well-rounded boulders. The dominant transport mechanism for both is the current generated by the storm surges. A secondary and important transport mechanism is wind transport. Wave generated currents under more minor storm conditions are probably also capable of moving sands along the shoreline. Currents in the pocket where the harbor resides are generally in a clockwise direction and prior to deep-draft harbor construction probably resulted in the harbor area fluctuating between being a sediment sink and a sediment source for down-flow beaches. The position of the Salt Lagoon entrance has shifted several hundreds of feet over brief periods of time, indicating insufficient boulders in the material being transported to armor and hold its position beyond its present northerly location.

Prior to deep-draft harbor construction, sediment accumulation in the area was limited and most accumulations were shifted in down transport after brief periods of storage in the lagoon entrance. Since construction of the breakwaters the currents have been modified, and the sediments reaching the harbor are retained in the area south of the east entrance in the general area from the entrance to the historic Salt Lagoon channel. Storm surges and the current driving mechanisms, however, are still similar to pre-construction. Since construction sediment accumulation within the confines of the deep-draft harbor appears to be less than 2,000 cubic yards per year, however, precise measurements of infill have not been made and the 2,000 yards could be exceeded. The observed accumulation is in the northeastern segment of the harbor and is not expected to encroach on Federal facilities for 5 years. A sediment management area (sediment trap) just inside the north breakwater between Boulder Spit and the wave dissipater island will trap and control most sediment entering the harbor. A sediment trap in this area when over dredged also helps prevent water quality degradation in Salt Lagoon.

Much of the sediment approaching the harbor is diverted westward along the deep-draft exterior detached breakwater and recirculated to the ocean about 1000 ft offshore of its previous location to the existing project circulation path shown in Figure A-12. This probably results in some deficit of sediments along the headlands to the west and may extend into Zolotoi Bay. The small boat harbor does not affect these conditions.

The dunes at the southern end of the harbor development are evidence of wind transport. It is expected that some sediment accumulation in the southeastern portion of the small boat harbor will result from the strong northerly winds blowing along the length of the spit.

7.5 Construction Dredging

Initial construction would involve dredging material consisting of up to 50 percent boulders to the project limits in the deep-draft entrance channel, maneuvering basin, sediment management area and entrance to the Salt Lagoon. Dredging in the small boat harbor should encounter a lower concentration of boulders. The small boat harbor dredging will comprise 140,000 cy of a total of 549,000 cy. Disposal will be at an upland disposal area, in the spending beach island on the south side of the detached breakwater, and on the beach fill on the southern boundary of the harbor.

7.6 Operation and Maintenance Plan

Operation of the completed project would for the major part be the city of St. Paul's responsibility. The federal government would be responsible for the breakwater, entrance and maneuvering channel. The Alaska District would conduct hydrographic surveys at 3- to 5-year intervals for dredging areas. The hydrographic surveys would be used to verify whether the predicted maintenance-dredging interval is adequate for the entrance and maneuvering channel. The expected maintenance is listed below.

Federal Channel Dredging - Minor accumulations can be managed in conjunction with deep-draft harbor maintenance. Sea source sediments enter through the deep-draft channel on the West and will accumulate in the maneuvering basin of the deep-draft harbor. Minor amounts of suspended fines may find their way into the Federal channel associated with the small boat harbor, but the amounts should be negligible. Sea source sediments at the western end of the project enter along the spit and accumulate in the deep-draft harbor and Salt Lagoon sediment management area. Minor amounts of fines may enter the federal channel of the small boat harbor but can be managed with the periodic management of in the deep-draft maneuvering area. It is assumed that 10,000 cyds will require removal on a 10-year frequency and assumed that mobilization and the deep-draft project will absorb any special costs for development of disposal areas.

Harbor Dredging - 4,000 cyds at 10-year intervals is the expected harbor dredging volume. Wind-driven sands from the boulder spit will cause the accumulation. The sands will accumulate in the eastern portion of the harbor.

Breakwater - The breakwater maintenance is anticipated to be less than 1%/yr with periodic maintenance of 20% of first cost.

Boat Ramp - The boat ramp will require 50% replacement at years 20 and 40. Those replacements will coincide with major breakwater repairs or with the major construction so as to negate the need for major mobilization costs. Repairs are expected to be $100,000 at 20-year intervals.

Floats and Walkway Ramps - Floats and walkway ramps will be left in place throughout the winter. They will require annual repairs of surfaces, mooring bits, pile attachments, piles, hinges and other items. The annual maintenance is estimated at 2.5% of the initial cost for years 1 through 5 and at 5% of the initial cost annually throughout the remainder of project life.

Breakwater Eastside Floating Dock - The floating dock will be left in place throughout the winter and receive heavy use throughout the year. It will require annual repairs of surfaces, mooring bits, pile attachment, piles, hinges and other items. The annual maintenance is estimated at 2.5% of the initial cost for years 1 through 5 and at 5% of the initial cost annually for the remainder of project life.

South Side Dock - The dock will require annual repairs of surfaces, mooring bits, piles, and other items. The annual maintenance is estimated at 2.5% of the initial cost for year 1 through 5 and at5% of the initial cost annually throughout the remainder of project life.

Boat Lift Trailer - The boat lift trailer will require $1,000 in annual maintenance. The maintenance will consist of lubrication, periodic replacement of straps, tires, hydraulic seals and general minor repairs.

7.6 Aids to Navigation

For the deep-draft channel a self-contained signal lantern has been installed at the head of the existing breakwater as an aid to navigation. Discussions with the U.S. Coast Guard have been conducted to assure that necessary marking of reefs and/or the entrance channel with ranges or lights would be considered. The small boat basin will require some additional buoys to mark the channel.

8. QUANTITIES AND COST ESTIMATES

8.1 Preferred Plan

Detailed estimates of quantities for dredging, and the local sponsor's costs for associated items were made for the recommended harbor plan. Other plans required to develop the NED or recommended plan were estimated based on this single detailed estimate. Dredging quantities were estimated for general navigation features and for other features. The general navigation features include the entrance channel, maneuvering channel, and the breakwater. The detailed cost estimate and associated quantities for the recommended plan are shown in MCACES format in the Economic Appendix.

8.2 Other Alternatives

A total of five plans were analyzed to arrive at the NED plan. The preferred plan is thoroughly described elsewhere in this report. Of the plans examined 3 are variation in depths for a 60-vessel harbor. All of the 60-vessel harbors require the deep inlet channel to obtain adequate flushing gyres. They also require a vessel haul-out ramp and most facilities needed in alternative depth harbors. Therefore, costs are similar to one another.

A 30-vessel harbor cost was examined at the -12' MLLW depth. Modeling efforts indicate that this harbor would perform adequately, but most major cost items are similar to the 60-vessel harbor.

A 90-vessel harbor was examined and may appear desirable based on harbor costs alone; however, there are both land use and environmental faults with this plan. The 90-vessel harbor expansion would require land either on the eastern or southern boundary of the proposed 60-vessel harbor. Model studies indicate that the 60-vessel harbor approaches the limits of secondary gyre, and transfer of basin waters will occur in a satisfactory manner. Further penetration into the shorelines will adversely affect water quality in those penetrations. There is a further problem with the 90-vessel harbor: Adjacent lands must be foregone for basin development. The giving up of these lands constrains reasonable associated harbor development.

9. CONSTRUCTION SCHEDULE

9.1 General

Major construction items to be undertaken concurrently with this project include constructing the spending beach and dredging the entrance channel, maneuvering basin, sediment management area and new Salt Lagoon entrance. In addition, the Salt Lagoon entrance would be stabilized and the spending beach constructed. The spending beach would be one area for disposal.

The time needed for construction is estimated at less than 6 months but will represent two construction seasons, as mobilization, demobilization and entrance dredging must be scheduled around seasons conducive to their accomplishment. Moorings and docks would be constructed during a second season.

Construction scheduling would facilitate the continued use of the harbor by local fishermen, fish processing facilities, and cargo vessels during construction. Project specifications would direct the contractor to conduct certain activities during specified time periods to allow continued harbor usage.

9.2 Effects of Harbor Improvements Construction

Construction of the St. Paul Harbor improvements would not impact the relatively quiescent waters within Village Cove and would not affect the wave climate or sediment supply of adjacent shorelines south and west of Village Cove. Improvements in the Federal project area (maneuvering and entrance channel) would not adversely impact the adjacent inner harbor areas or tidelands outside the harbor. Shoaling at the deep-draft harbor entrance or inside the deep-draft harbor would not be increased by development of the small boat harbor.

Water circulation within Village Cove is driven predominantly by tidal action and high wind fields, which the proposed improvements would not impact. Model studies indicate that circulation would be considerably enhanced by wave action during storm conditions and that enhancement is not compromised by the small boat harbor development.

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Table 1
Short Period Wave Heights for Plan 28

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
8	10	2.3	0.6	1.1	0.3	0.6	0.3	0.1	0.2	0.2	0.2	0.7
10	10	2.6	0.7	0.9	0.5	0.8	0.4	0.2	0.2	0.3	0.2	0.9
16	14.4	3.5	1.2	1.5	1.4	1.3	0.9	0.3	0.4	0.5	0.4	1.3
16	19	4.2	1.4	1.7	1.6	1.4	1.0	0.4	0.5	0.6	0.5	1.4
20	14	4.0	1.4	1.7	1.5	1.4	0.9	0.4	0.5	0.6	0.5	1.5
25	5	2.0	1.0	1.7	1.3	1.2	0.6	0.1	0.2	0.3	0.2	0.6
swl = +7.0 ft												
8	10	2.8	1.0	1.0	0.8	0.7	0.5	0.2	0.2	0.3	0.3	0.7
10	10	3.5	1.0	1.1	0.8	0.9	0.7	0.3	0.3	0.4	0.3	1.0
16	14.4	4.6	1.6	2.0	1.6	1.4	1.1	0.5	0.5	0.7	0.6	1.8
16	19	5.6	2.0	2.6	1.9	1.8	1.3	0.6	0.6	0.8	0.7	2.2
20	14	4.8	1.7	2.2	1.8	1.6	1.1	0.5	0.6	0.7	0.6	2.0
25	5	2.5	0.8	1.1	1.1	1.2	0.9	0.2	0.3	0.4	0.3	0.9

Table 2
Long Period Wave Heights for Plan 28

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
8	10	2.4	0.7	1.2	0.5	0.8	0.6	0.7	0.9	0.6	0.6	1.0
10	10	2.9	1.0	1.3	1.1	1.3	1.1	1.1	1.3	0.8	0.9	1.4
16	14.4	4.0	1.7	2.2	2.4	2.0	1.8	1.7	2.0	1.6	1.6	2.0
16	19	4.7	2.0	2.4	2.6	2.3	1.9	2.3	1.8	1.6	1.8	2.2
20	14	4.5	2.0	2.4	2.4	2.4	1.8	1.9	2.0	1.4	1.6	2.4
25	5	2.1	0.7	1.1	1.0	0.9	0.6	0.5	0.7	0.6	0.6	0.8
swl = +7.0 ft												
8	10	2.8	1.1	1.1	0.9	0.9	0.8	0.9	1.1	0.6	0.7	1.1
10	10	3.6	1.2	1.3	1.2	1.3	1.1	1.2	1.2	0.9	1.0	1.4
16	14.4	5.0	2.0	2.6	2.5	2.2	1.7	1.9	2.1	1.5	1.8	2.6
16	19	6.1	2.6	3.1	3.1	2.6	1.9	2.0	2.1	1.7	1.7	3.2
20	14	5.3	2.2	2.9	2.9	2.5	1.9	2.0	2.2	1.6	1.8	2.8
25	5	2.6	0.9	1.2	1.2	0.9	0.7	0.6	0.7	0.6	0.6	1.0

Table 3
Comparison of Wave Heights for Plans 28-32; 16-sec, 19-ft waves; swl = +3.2 ft

Plan	Wave Height at Indicated Gauge Location, ft										
	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
Short Period Wave Conditions											
28	4.2	1.4	1.7	1.6	1.4	1.0	0.4	0.5	0.6	0.5	1.4
29	4.2	1.3	1.7	1.5	1.4	0.9	0.3	0.5	0.6	0.5	1.4
30	4.0	1.4	1.7	1.5	1.4	0.9	0.4	0.4	0.6	0.5	1.3
31	4.1	1.3	1.8	1.6	1.3	0.9	0.4	0.5	0.5	0.5	1.4
32	4.5	1.4	1.8	1.6	1.4	0.9	0.3	0.4	0.5	0.5	1.4
Long Period Wave Conditions											
28	4.7	2.0	2.4	2.6	2.3	1.9	2.3	1.8	1.6	1.8	2.2
29	4.6	1.9	2.4	2.3	2.3	1.6	1.9	1.8	1.4	1.6	2.1
30	4.6	1.9	2.5	2.3	2.1	1.7	1.8	1.5	1.4	1.5	2.1
31	4.7	1.9	2.4	2.4	2.1	1.6	1.9	1.7	1.4	1.7	2.2
32	5.0	2.0	2.7	2.6	2.3	1.6	1.9	1.6	1.4	1.6	2.1

Table 4
Short Period Wave Heights for Plan 32

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.5	0.7	0.9	0.7	0.7	0.5	0.2	0.2	0.3	0.2	0.9
16	19	4.5	1.4	1.8	1.6	1.4	0.9	0.3	0.4	0.5	0.5	1.4
20	14	4.0	1.3	1.8	1.5	1.5	0.9	0.3	0.3	0.5	0.4	1.3
25	10	3.3	1.1	1.6	1.5	1.2	0.8	0.3	0.3	0.4	0.4	1.1
swl = +7.0 ft												
10	10	3.3	1.0	0.7	0.6	1.1	0.6	0.2	0.3	0.4	0.3	1.0
16	19	5.0	1.8	1.8	1.7	2.1	1.0	0.4	0.6	0.7	0.6	2.0
20	14	4.6	1.6	1.7	1.7	1.5	1.0	0.4	0.6	0.6	0.6	1.9
25	10	4.4	1.4	1.6	1.8	1.5	0.9	0.3	0.4	0.6	0.5	1.6

Table 5
Long Period Wave Heights for Plan 32

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.7	1.0	1.4	1.2	1.2	1.0	1.1	1.2	0.8	0.9	1.3
16	19	5.0	2.0	2.7	2.6	2.3	1.6	1.9	1.6	1.4	1.6	2.1
20	14	4.4	1.9	2.6	2.4	2.5	1.6	1.7	1.4	1.3	1.5	2.2
25	10	3.7	1.5	2.2	2.1	1.8	1.3	1.4	1.7	1.2	1.4	1.6
swl = +7.0 ft												
10	10	3.4	1.2	1.1	1.1	1.5	0.9	1.2	1.1	0.7	0.9	1.4
16	19	5.6	2.5	2.6	3.0	3.0	1.7	2.5	2.1	1.5	1.7	2.8
20	14	5.1	2.2	2.5	2.7	2.4	1.6	2.0	2.0	1.5	1.7	2.8
25	10	4.7	1.8	2.1	2.4	2.1	1.5	1.5	1.5	1.2	1.3	2.2

Table 6
Comparison of Wave Heights for Plans 33-35; 16-sec, 19-ft waves; swl = +3.2 ft

Plan	Wave Height at Indicated Gauge Location, ft										
	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
Short Period Wave Conditions											
33	4.3	1.4	0.5	1.6	1.2	0.8	0.3	0.4	0.5	0.4	1.5
34	4.3	1.4	0.5	1.6	1.3	0.9	0.3	0.4	0.5	0.4	1.6
35	4.2	1.3	0.5	1.6	1.3	0.9	0.3	0.4	0.5	0.4	1.5
Long Period Wave Conditions											
33	4.8	2.1	2.9	2.5	2.2	2.1	2.4	2.2	1.9	1.7	2.5
34	4.7	2.0	3.2	2.8	2.3	1.6	2.3	2.7	1.9	1.9	2.3
35	4.6	1.9	3.1	2.6	2.3	1.8	2.0	2.3	1.5	1.9	2.3

Table 7
Short Period Wave Heights for Plan 37

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.1	0.6	0.3	0.7	0.5	0.3	0.2	0.3	0.2	0.2	0.6
16	19	4.2	1.4	0.6	1.6	1.0	0.8	0.4	0.4	0.6	0.4	1.5
20	14	3.5	1.2	0.5	1.5	1.0	0.7	0.4	0.4	0.4	0.4	1.1
25	10	3.1	0.9	0.4	1.5	0.9	0.6	0.2	0.3	0.4	0.3	0.9
swl = +7.0 ft												
10	10	3.7	1.0	0.3	0.8	0.6	0.3	0.3	0.3	0.5	0.3	0.8
16	19	5.4	1.8	0.7	1.8	1.5	0.9	0.6	0.7	0.8	0.6	2.3
20	14	4.8	1.7	0.6	1.8	1.4	0.8	0.6	0.6	0.8	0.6	2.0
25	10	4.5	1.5	0.5	2.0	1.2	0.6	0.5	0.5	0.7	0.5	1.7

Exhibit A5.5.2

Table 8
Long Period Wave Heights for Plan 37

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft												
10	10	2.5	0.9	2.1	1.3	1.0	1.0	1.2	1.2	0.8	0.9	1.2
16	19	4.7	1.9	3.4	2.7	2.0	1.9	2.2	2.2	1.6	2.0	2.3
20	14	4.1	1.8	3.0	2.4	2.0	1.7	1.9	2.0	1.3	1.6	2.0
25	10	3.5	1.3	2.6	2.3	1.6	1.4	1.9	1.8	1.8	1.6	1.4
swl = +7.0 ft												
10	10	3.7	1.2	2.2	1.3	1.3	1.1	1.3	1.4	0.9	1.0	1.2
16	19	5.8	2.4	4.0	3.1	2.7	1.8	2.4	2.4	1.9	2.1	3.5
20	14	5.3	2.3	4.0	2.9	2.5	1.9	2.4	2.7	1.8	2.0	2.8
25	10	4.8	1.9	2.9	2.7	1.9	1.5	2.0	2.1	1.5	1.7	2.3

Exhibit A5.4.3

Table 9
Short Period Wave Heights for Plan 38

Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3B	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11A
swl = +3.2 ft												
10	10	2.8	0.8	0.3	0.8	0.6	0.3	0.2	0.2	0.4	0.3	0.7
16	19	4.0	1.3	0.5	1.6	1.1	0.6	0.3	0.5	0.6	0.4	1.6
20	14	3.8	1.3	0.5	1.5	1.2	0.6	0.3	0.5	0.5	0.4	1.5
25	10	3.4	0.9	0.4	1.4	1.0	0.5	0.2	0.4	0.5	0.3	1.5
swl = +7.0 ft												
10	10	3.8	1.1	0.3	0.9	0.8	0.5	0.3	0.3	0.6	0.4	0.7
16	19	5.5	1.9	0.7	1.9	1.7	1.0	0.6	0.7	0.9	0.7	1.9
20	14	4.8	1.7	0.6	1.8	1.4	0.9	0.5	0.6	0.8	0.7	1.8
25	10	4.5	1.5	0.6	2.0	1.3	0.8	0.5	0.5	0.8	0.6	1.8

Table 10
Long Period Wave Heights for Plan 38

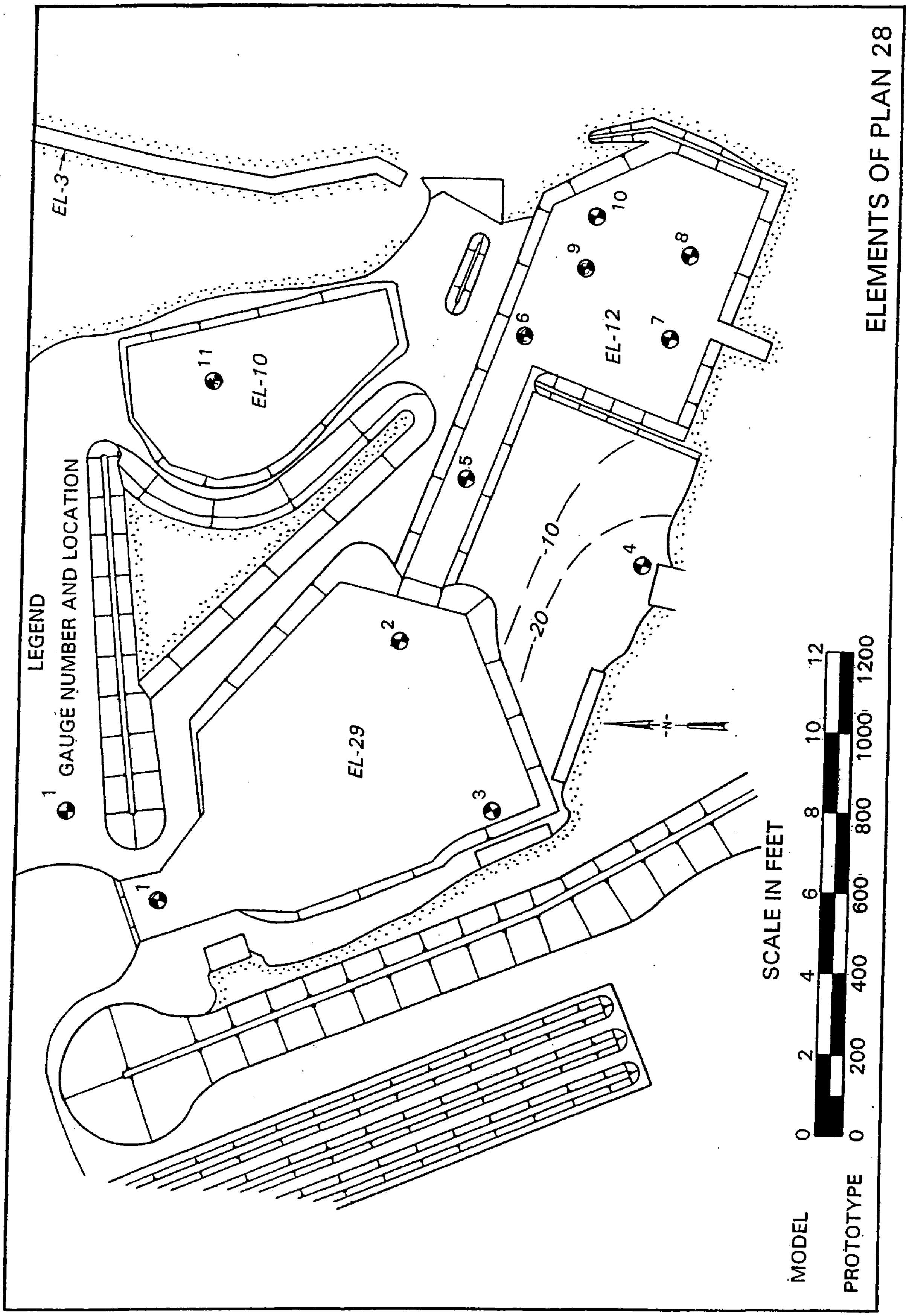
Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3B	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11A
swl = +3.2 ft												
10	10	3.2	1.0	2.0	1.4	1.2	1.0	1.6	1.6	1.0	1.4	2.5
16	19	4.6	1.9	3.0	2.6	2.0	1.9	2.1	2.3	1.7	2.2	4.6
20	14	4.3	1.8	2.7	2.4	2.1	1.5	1.8	2.0	1.4	2.2	4.3
25	10	3.8	1.3	2.4	2.2	1.8	1.4	1.8	1.9	1.5	1.8	3.6
swl = +7.0 ft												
10	10	3.9	1.3	1.9	1.4	1.2	1.0	1.4	1.6	1.0	1.2	2.3
16	19	6.0	2.5	3.7	3.3	2.7	1.8	2.7	3.0	1.9	2.6	5.4
20	14	5.3	2.2	3.6	3.0	2.6	1.8	2.5	2.9	1.9	2.5	5.1
25	10	4.9	2.0	2.7	2.8	2.0	1.6	2.1	2.3	1.6	2.0	3.9

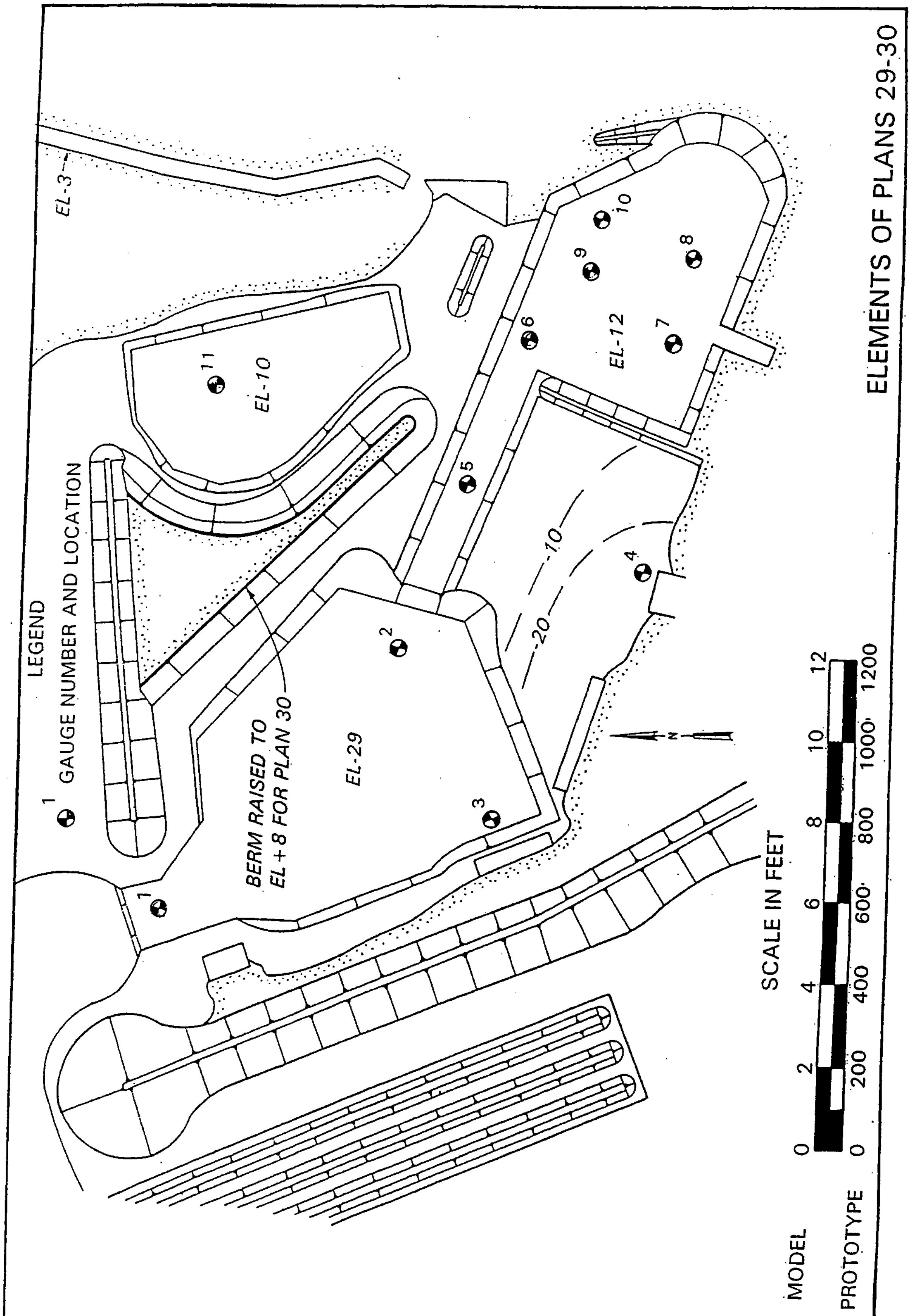
Table 11
Short Period Wave Heights for Plan 39

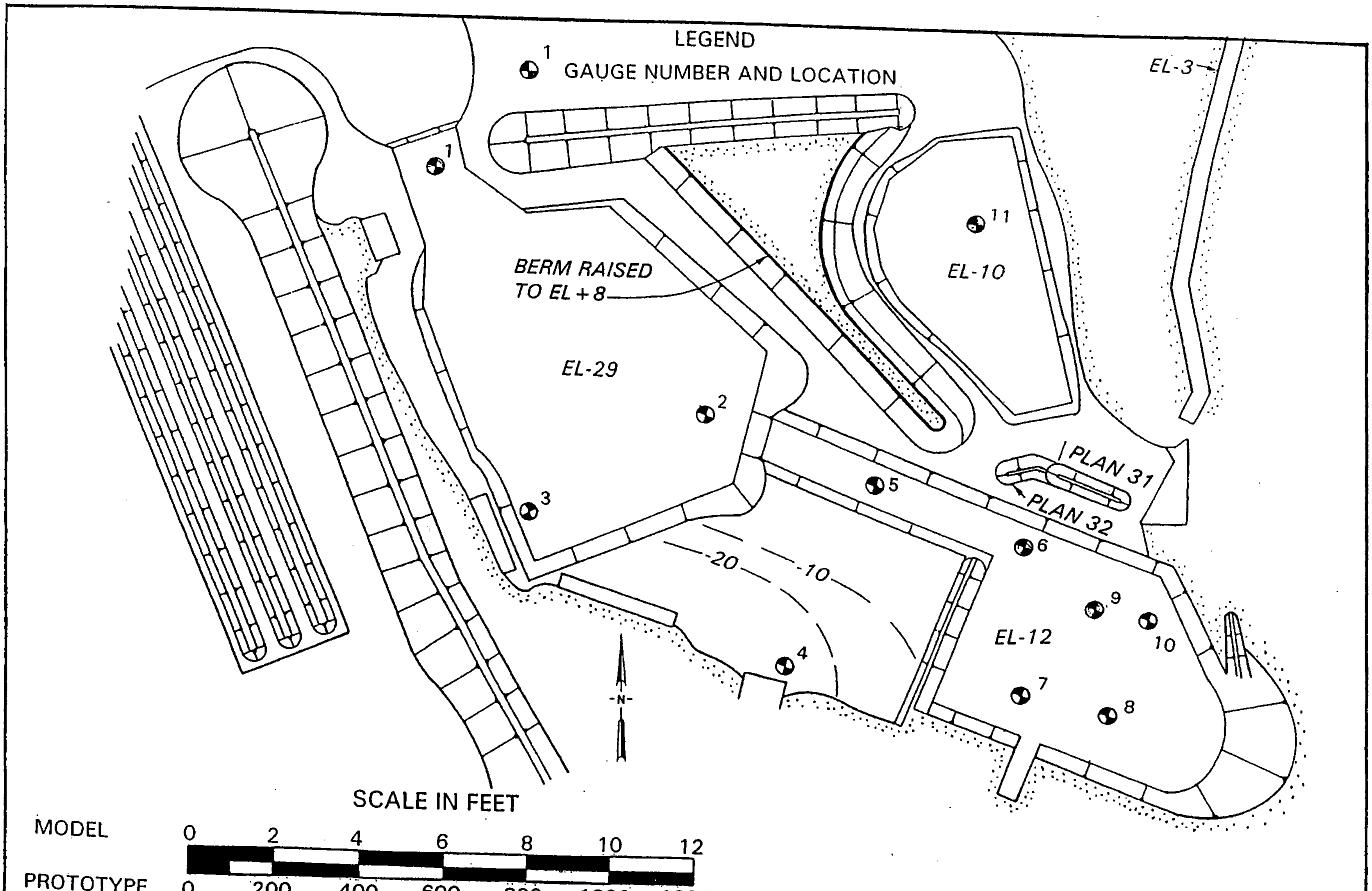
Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11A
swl = +3.2 ft												
10	10	2.2	0.6	0.3	0.8	0.4	0.3	0.2	0.2	0.2	0.2	0.8
16	19	4.1	1.2	0.6	1.8	1.0	0.7	0.4	0.4	0.5	0.4	1.7
20	14	3.9	1.2	0.6	1.7	1.0	0.6	0.4	0.4	0.5	0.4	1.7
25	10	3.2	0.8	1.0	1.5	0.7	0.5	0.3	0.3	0.4	0.3	1.6
swl = +7.0 ft												
10	10	3.6	1.0	1.0	1.3	0.8	0.4	0.2	0.3	0.3	0.3	0.8
16	19	5.8	2.0	1.2	2.4	1.7	1.1	0.7	0.7	0.8	0.6	1.8
20	14	4.9	1.6	1.4	2.2	1.5	0.9	0.6	0.6	0.7	0.5	1.7
25	10	4.6	1.4	1.0	2.2	1.2	0.7	0.5	0.5	0.6	0.4	1.7

Table 12
Long Period Wave Heights for Plan 39

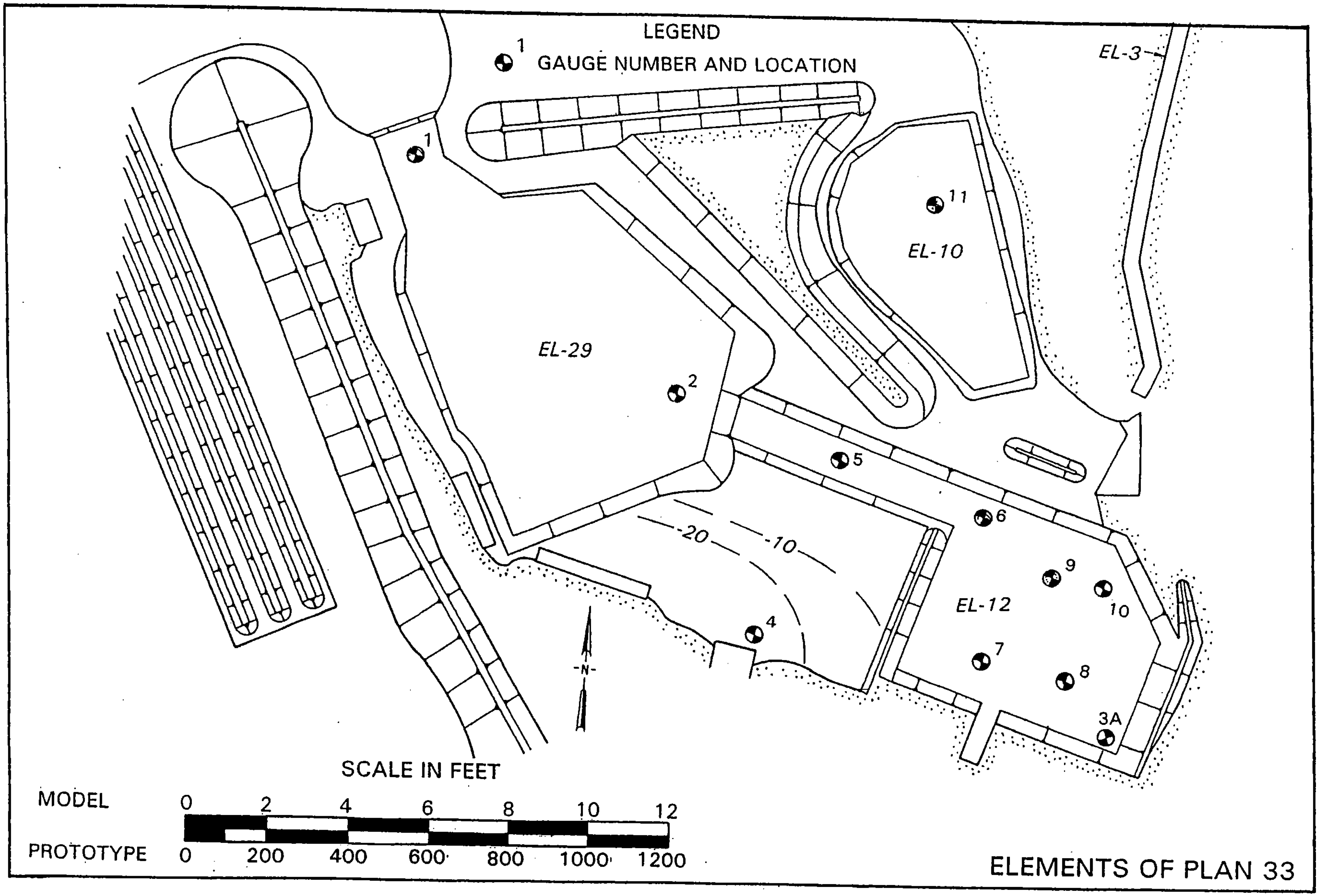
Experimental Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3A	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11A
swl = +3.2 ft												
10	10	2.4	0.9	2.2	1.3	1.0	1.3	1.3	1.5	1.2	1.3	2.4
16	19	4.6	1.7	3.5	2.7	2.0	2.0	1.9	2.5	1.8	2.1	4.3
20	14	4.3	1.7	3.6	2.6	1.9	1.8	2.0	2.4	1.5	1.9	4.2
25	10	3.5	1.2	3.6	2.4	1.5	1.7	2.1	2.2	1.6	2.0	3.3
swl = +7.0 ft												
10	10	3.8	1.2	3.2	1.6	1.1	1.2	1.5	1.5	1.0	1.2	1.9
16	19	6.4	2.7	4.1	3.8	2.6	2.1	2.7	3.0	2.1	2.5	4.9
20	14	5.6	2.3	4.1	3.2	2.3	2.1	2.9	3.0	2.1	2.4	4.6
25	10	5.0	1.9	3.6	3.0	1.8	1.7	2.2	2.1	1.6	1.9	3.5


ELEMENTS OF PLAN 28
LEGEND
GAUGE NUMBER AND LOCATION
EL-3
EL-10
EL-12
EL-29
1
2
3
4
5
6
7
8
9
10
11
-10
-20
N
SCALE IN FEET
MODEL
0 2 4 6 8 10 12
PROTOTYPE
0 200 400 600 800 1000 1200

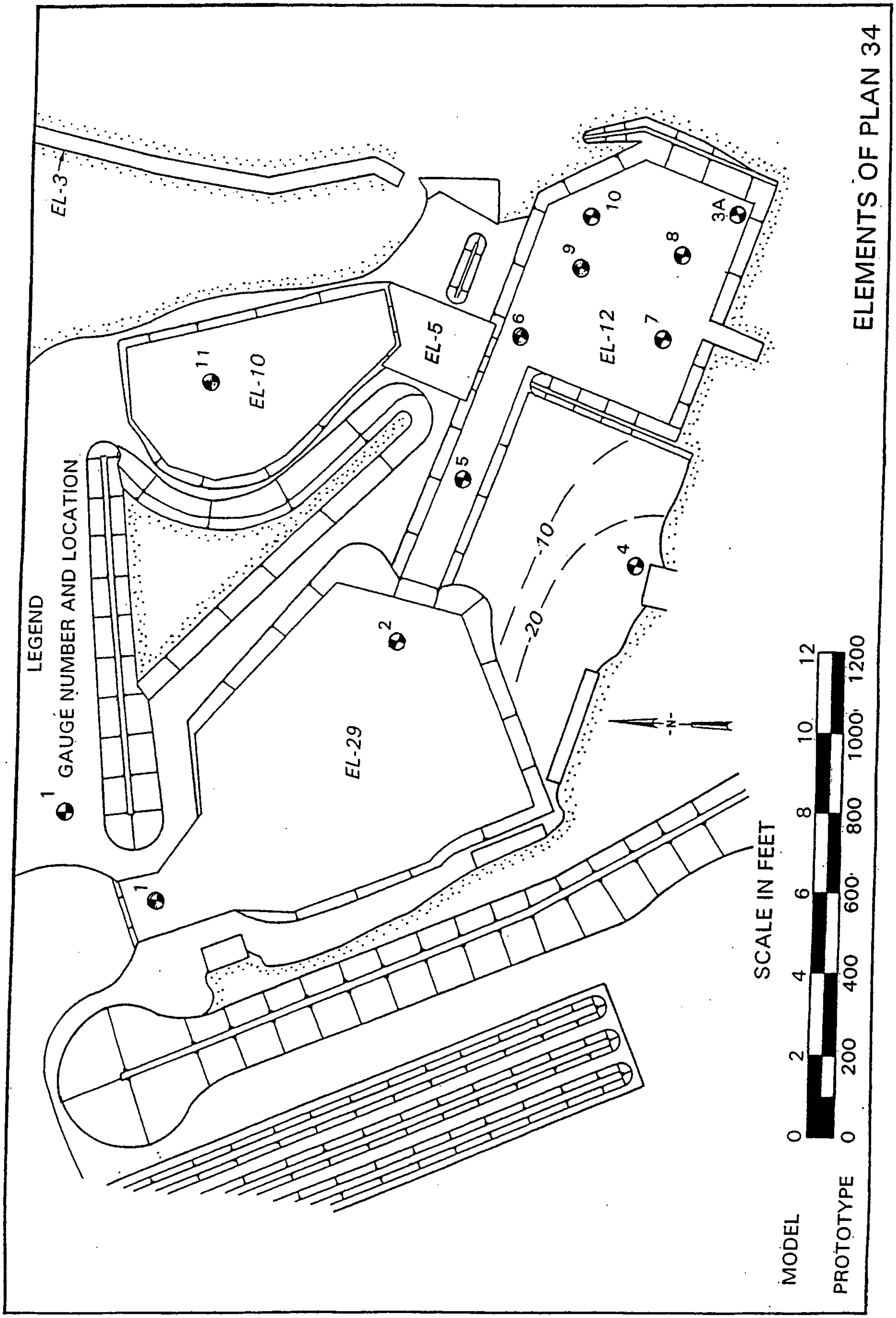

ELEMENTS OF PLANS 29-30
LEGEND
GAUGE NUMBER AND LOCATION
EL-3
EL-10
EL-12
EL-29
BERM RAISED TO
EL+8 FOR PLAN 30
-10
-20
N
SCALE IN FEET
MODEL
PROTOTYPE
0
2
4
6
8
10
12
0
200
400
600
800
1000
1200



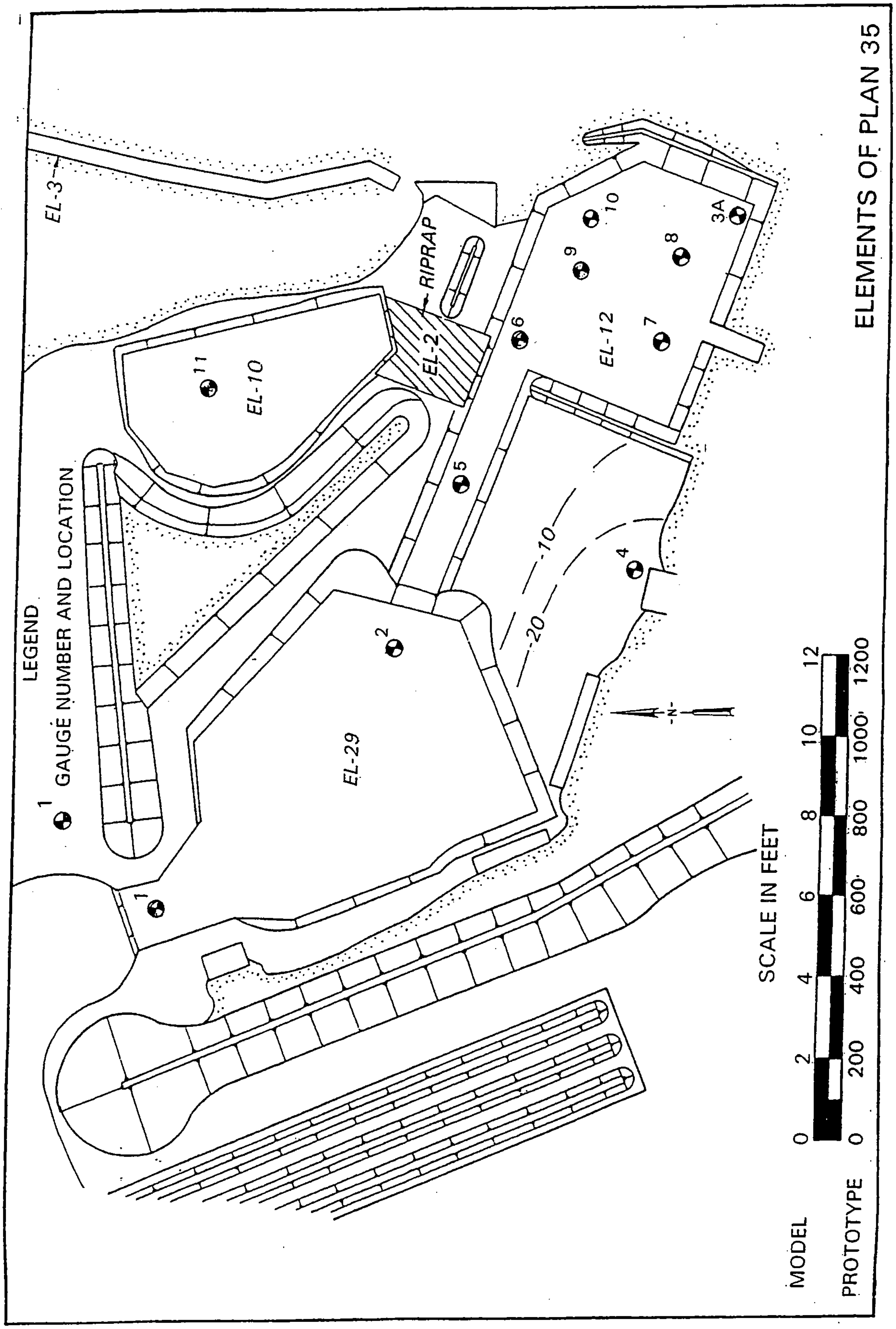
ELEMENTS OF PLANS 31-32



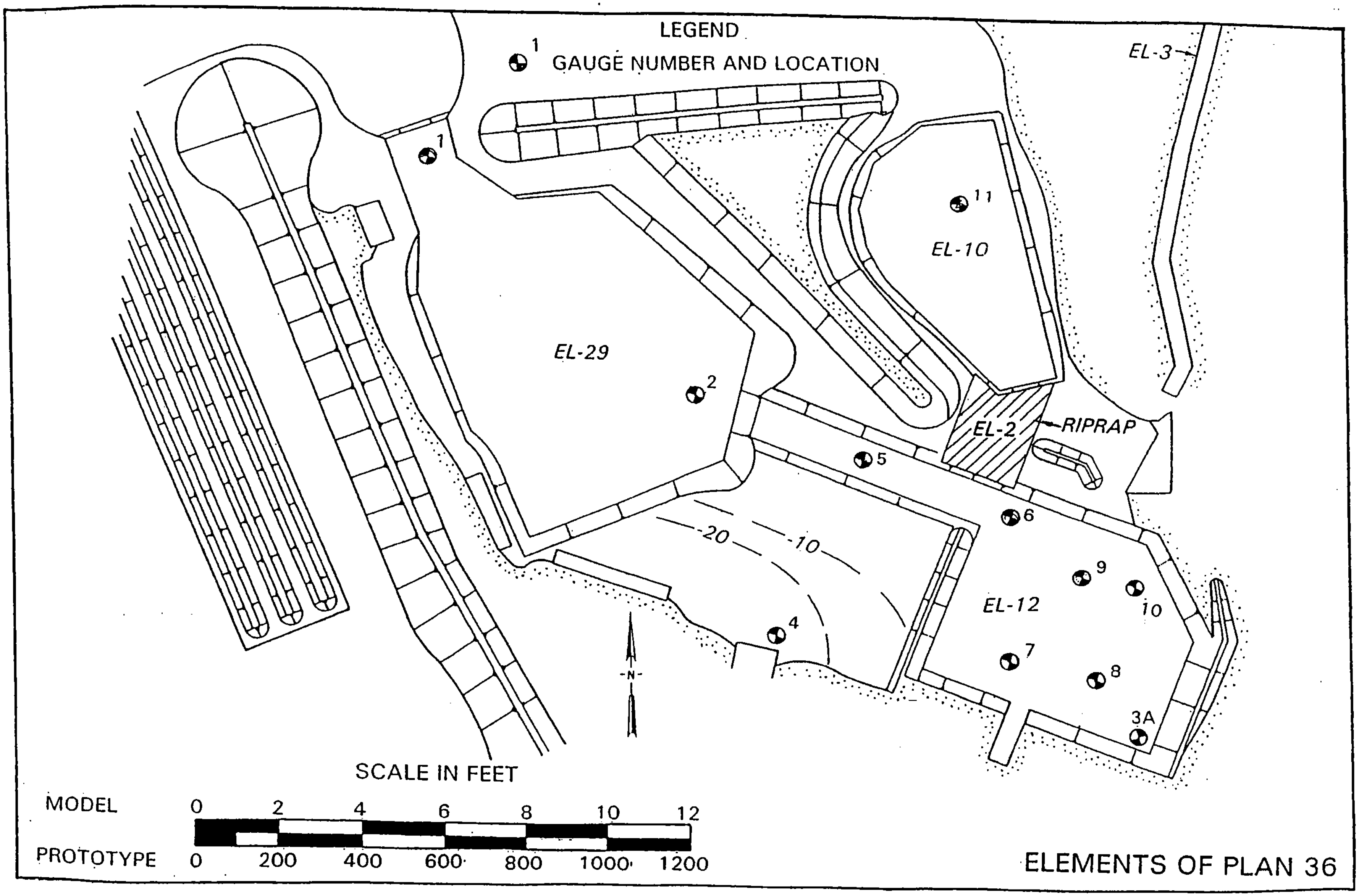
LEGEND
1 GAUGE NUMBER AND LOCATION
EL-3
EL-10
EL-29
EL-12
1
2
4
5
6
7
8
9
10
11
3A
-20
-10
N
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 200 400 600 800 1000 1200
ELEMENTS OF PLAN 33



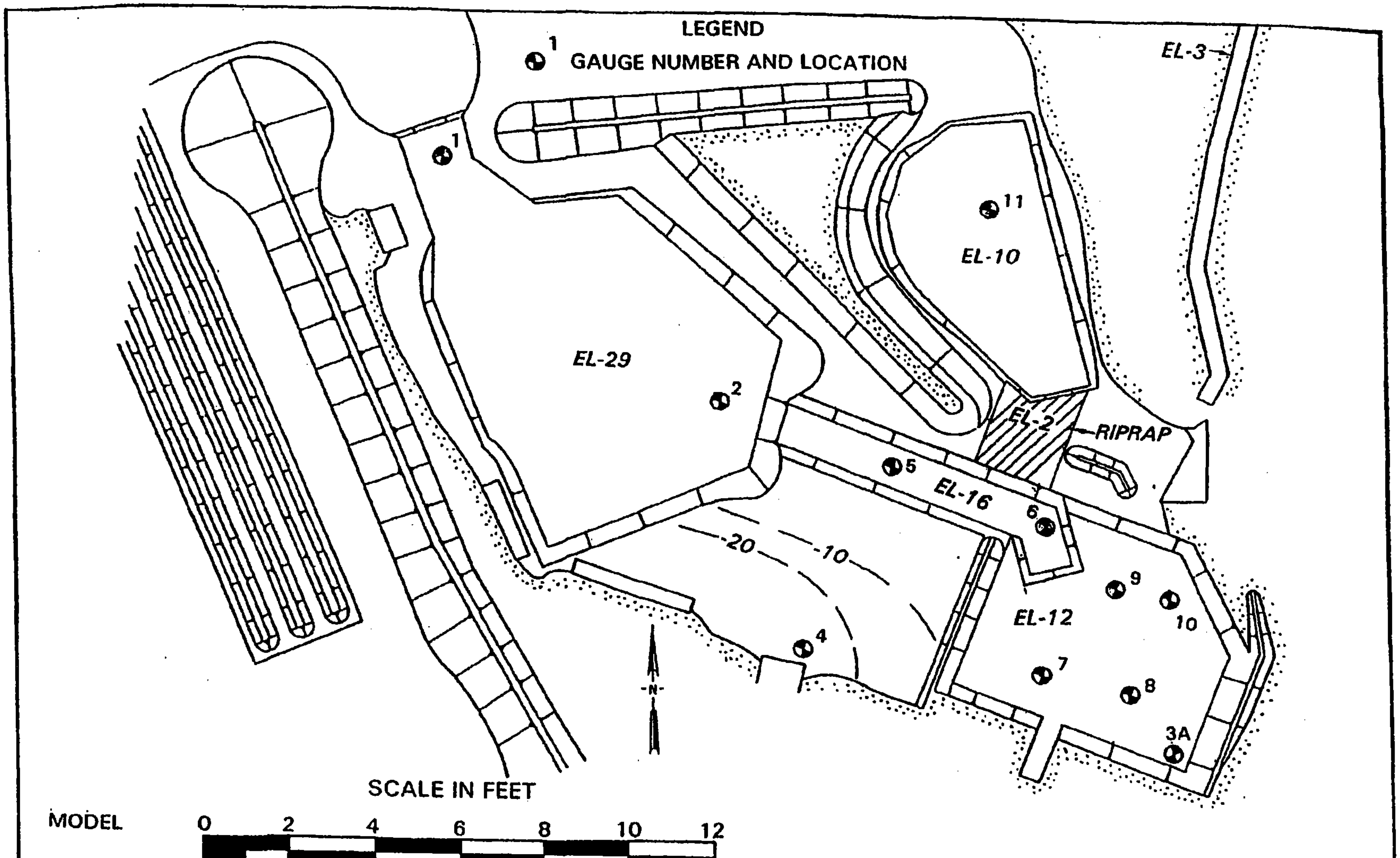
ELEMENTS OF PLAN 34
LEGEND
GAUGE NUMBER AND LOCATION
EL-3
EL-5
EL-10
EL-12
EL-29
1
2
3A
4
5
6
7
8
9
10
11
-10
-20
-N-
SCALE IN FEET
MODEL
PROTOTYPE
0 2 4 6 8 10 12
0 200 400 600 800 1000 1200



ELEMENTS OF PLAN 35
LEGEND
GAUGE NUMBER AND LOCATION
EL-3
EL-2
EL-10
EL-12
EL-29
RIPRAP
-10
-20
N
SCALE IN FEET
MODEL
PROTOTYPE
0
2
4
6
8
10
12
0
200
400
600
800
1000
1200

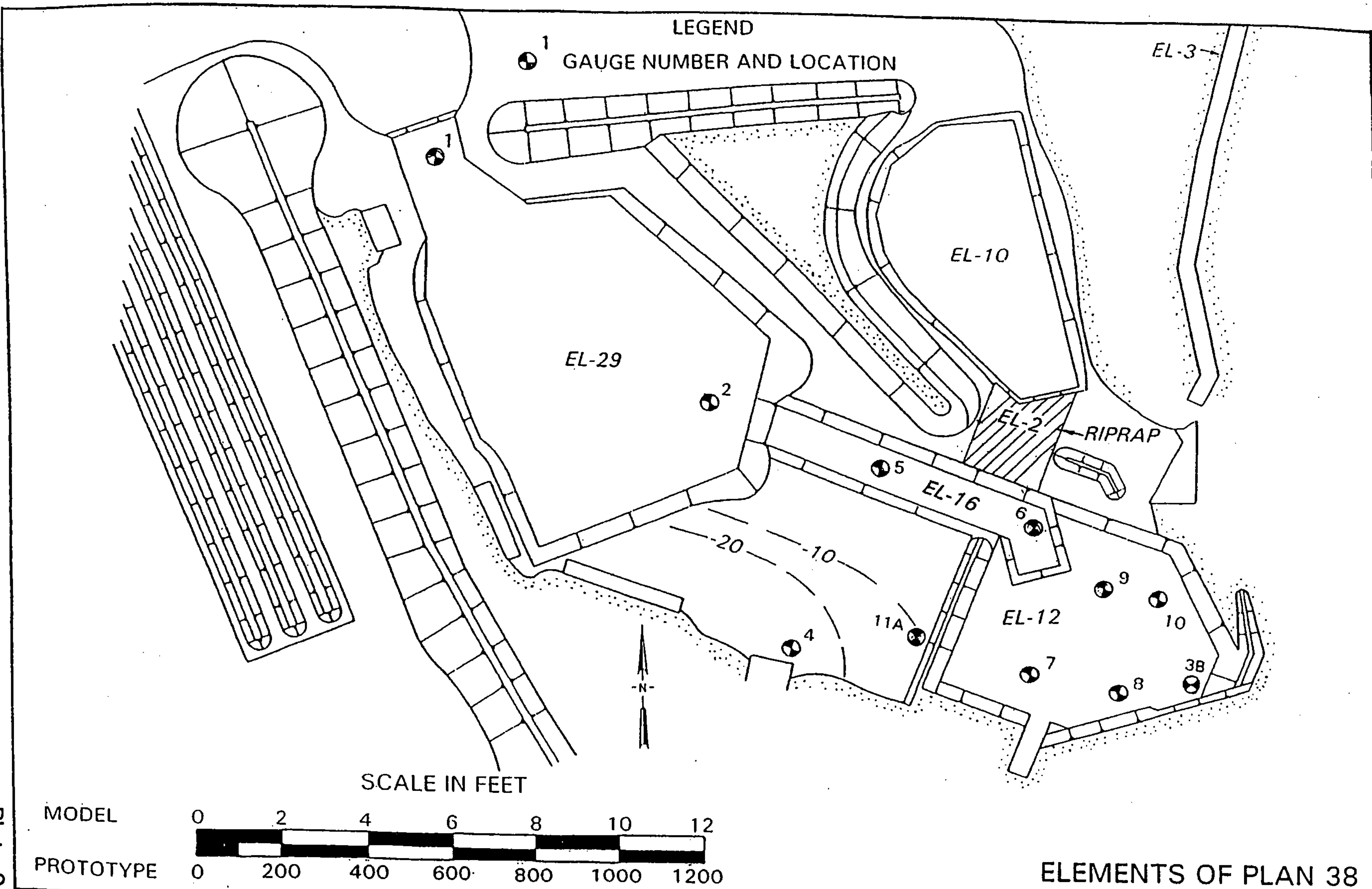


ELEMENTS OF PLAN 36

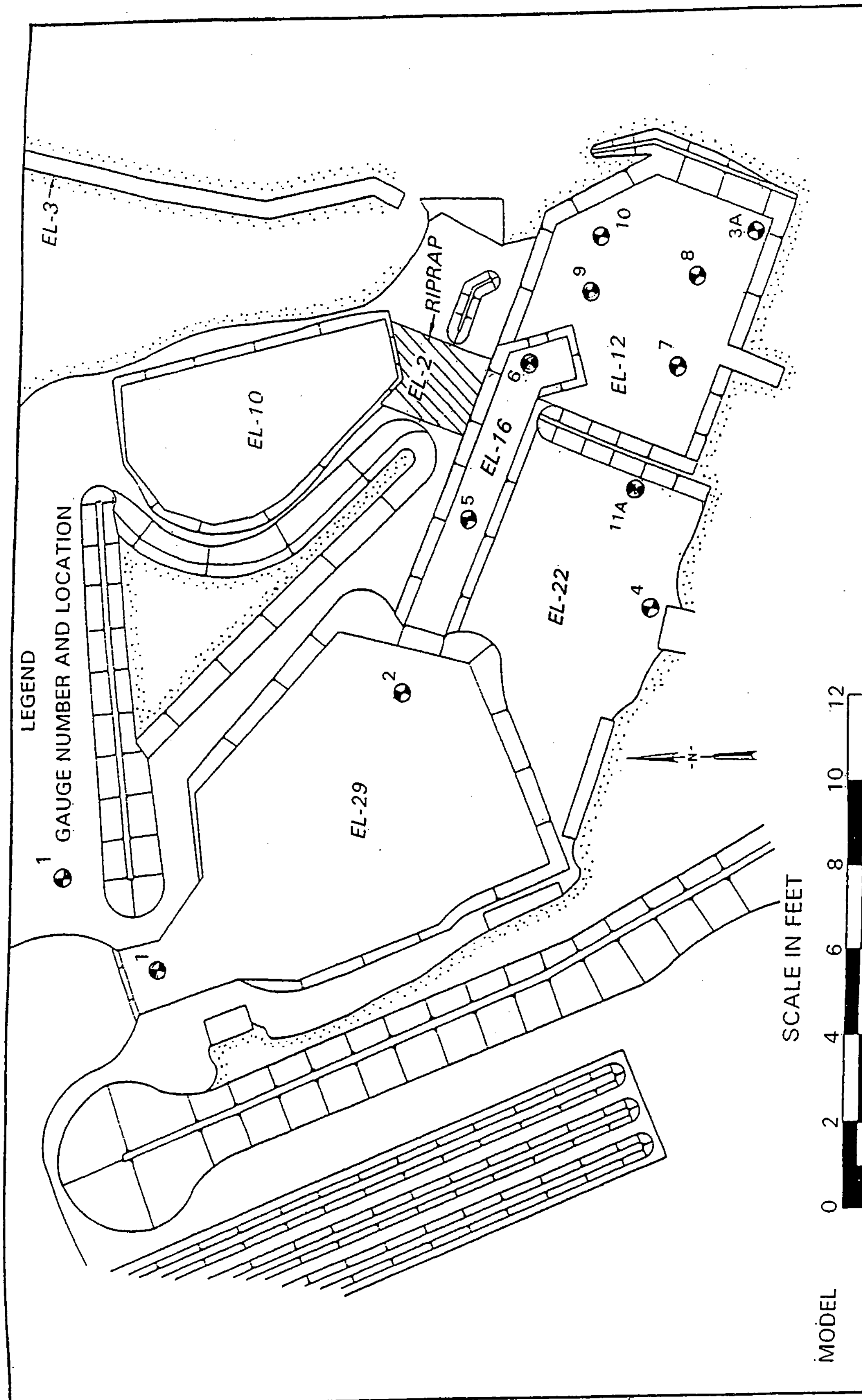


ELEMENTS OF PLAN 37

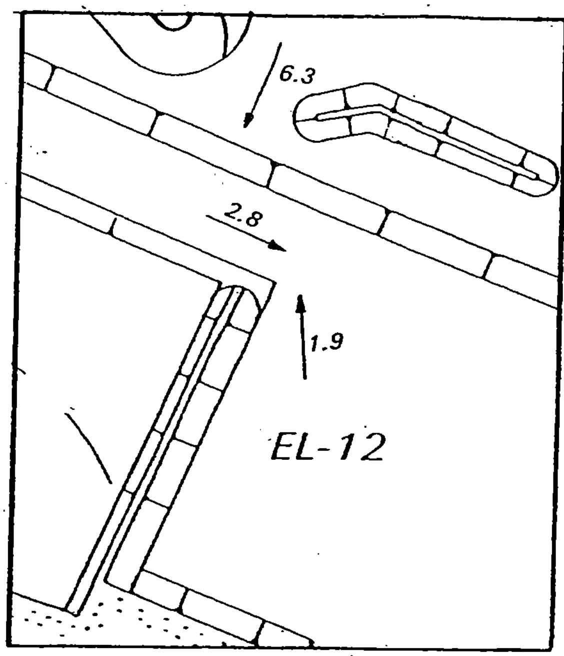
Exhibit A5.4.1



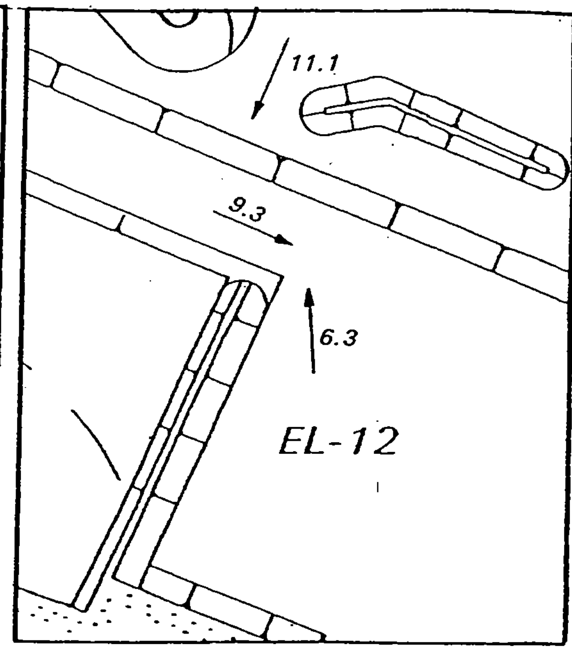
ELEMENTS OF PLAN 38



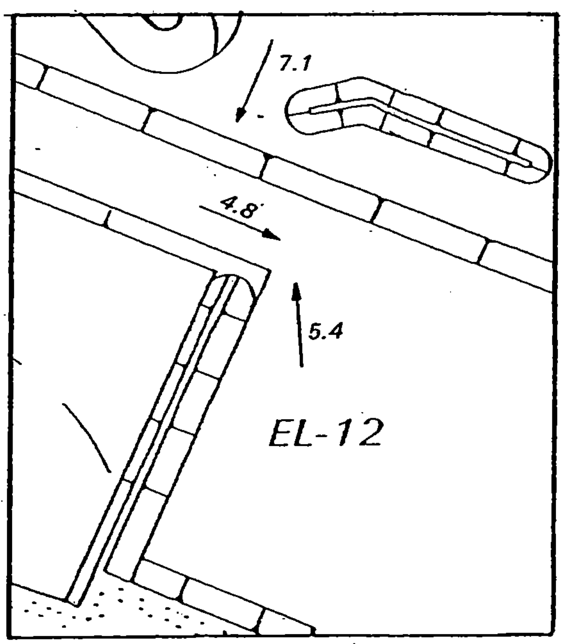
ELEMENTS OF PLAN 39



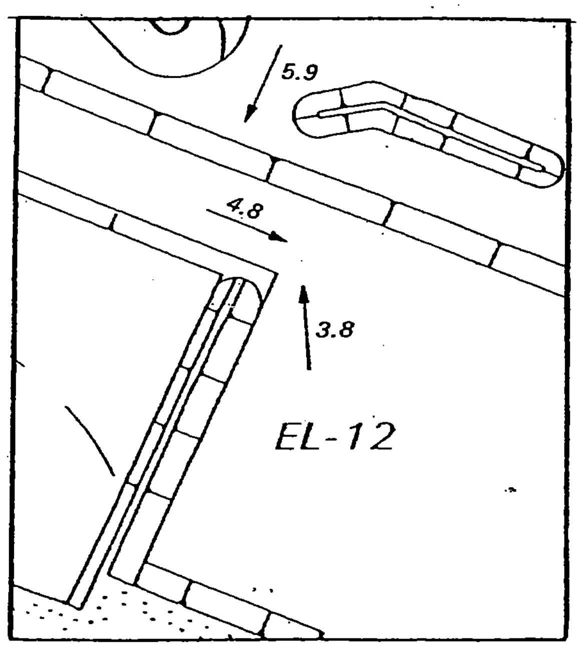
10-sec, 10-ft waves



16-sec, 19-ft waves

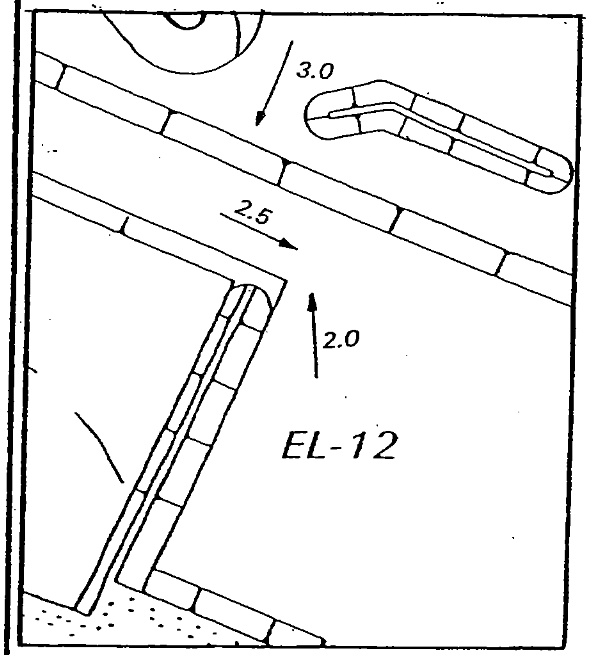


20-sec, 14-ft waves

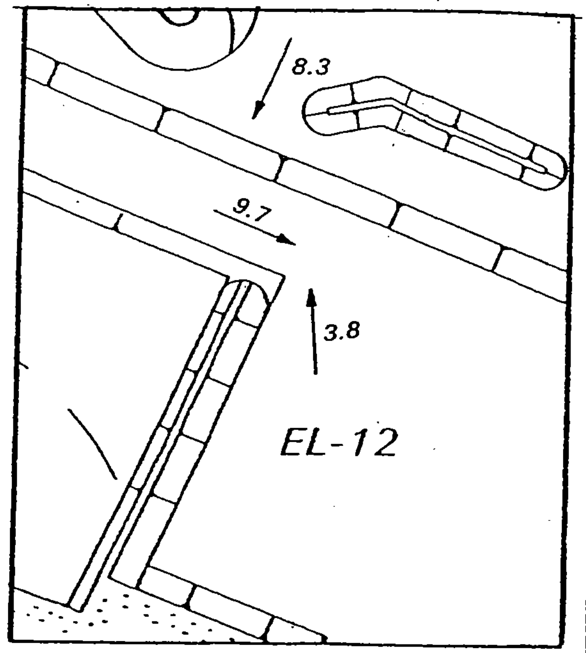


25-sec, 10-ft waves

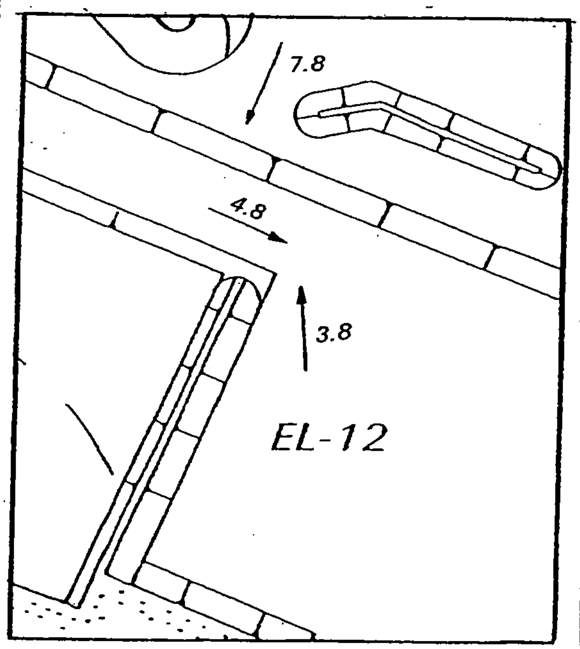
Wave induced current patterns and magnitudes (prototype feet per second) for Plan 32, swl = +3.2 ft



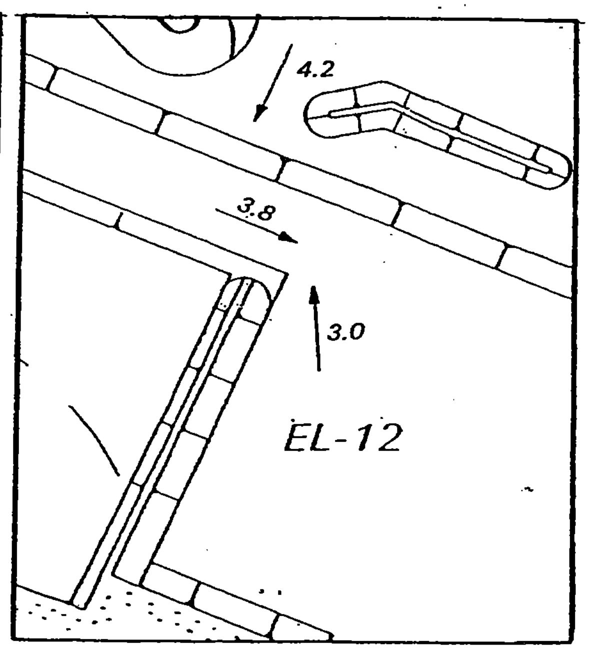
10-sec, 10-ft waves



16-sec, 19-ft waves

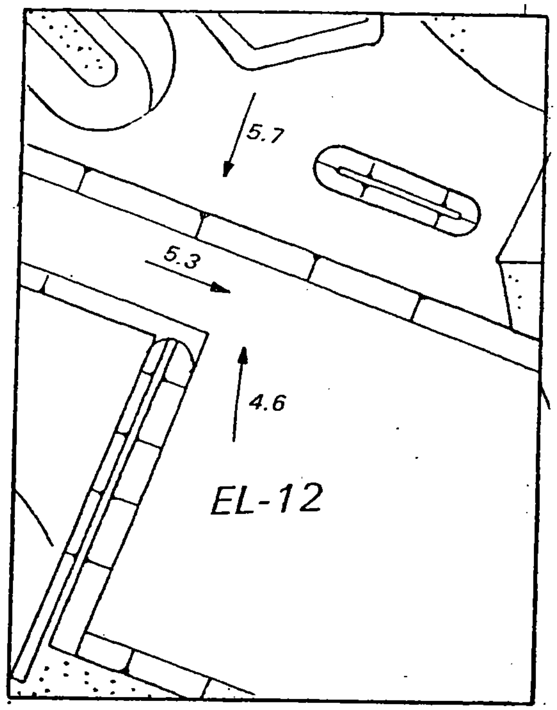


20-sec, 14-ft waves

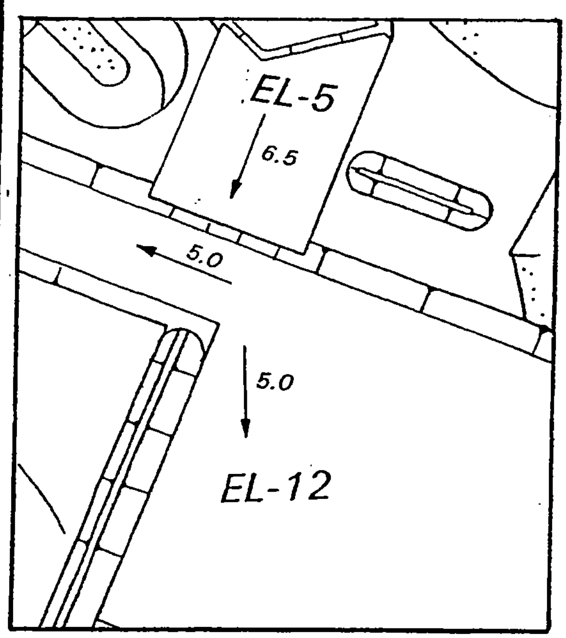


25-sec, 10-ft waves

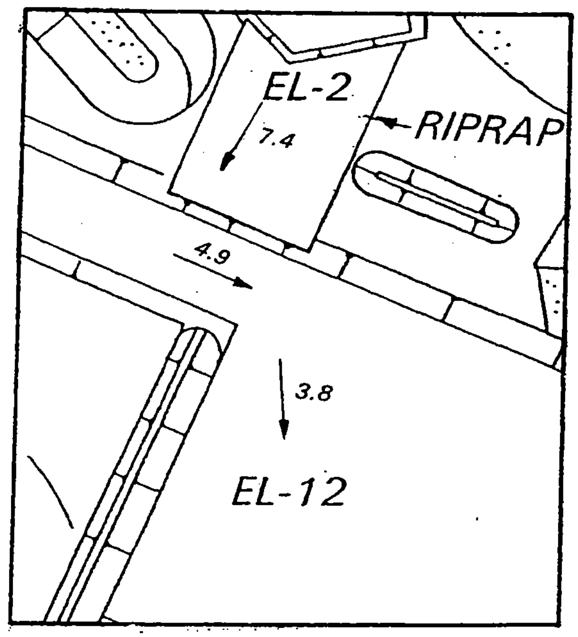
Wave induced current patterns and magnitudes (prototype feet Per second) for Plan 32, swl = +7.0 ft



Plan 33

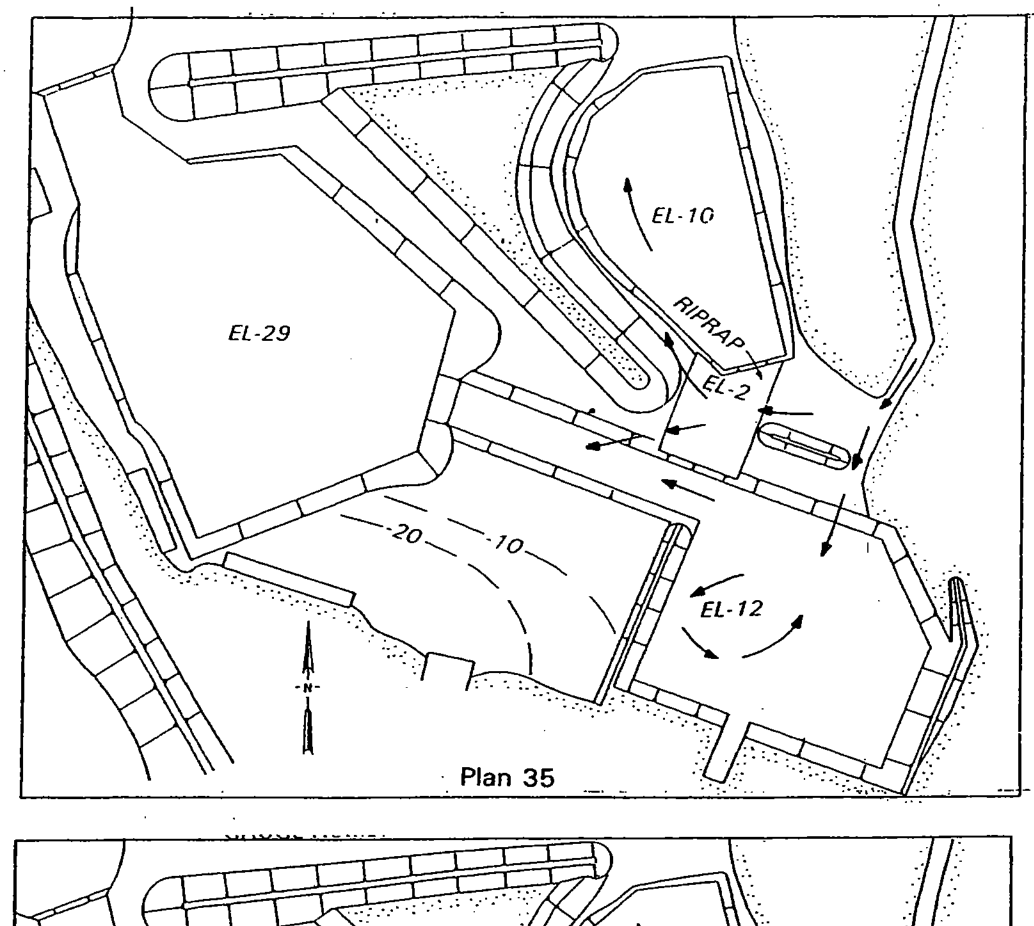


Plan 34

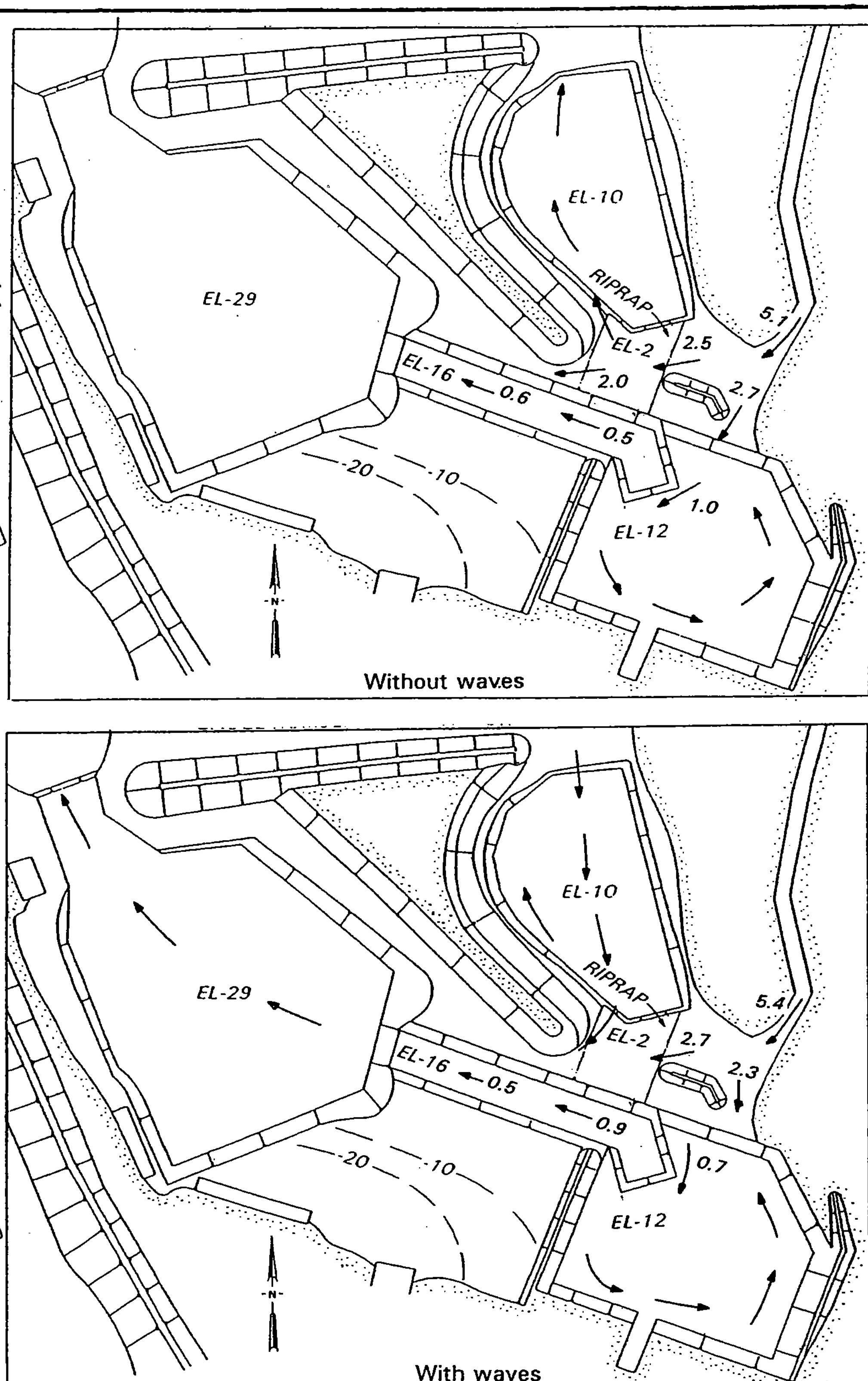


Plan 35

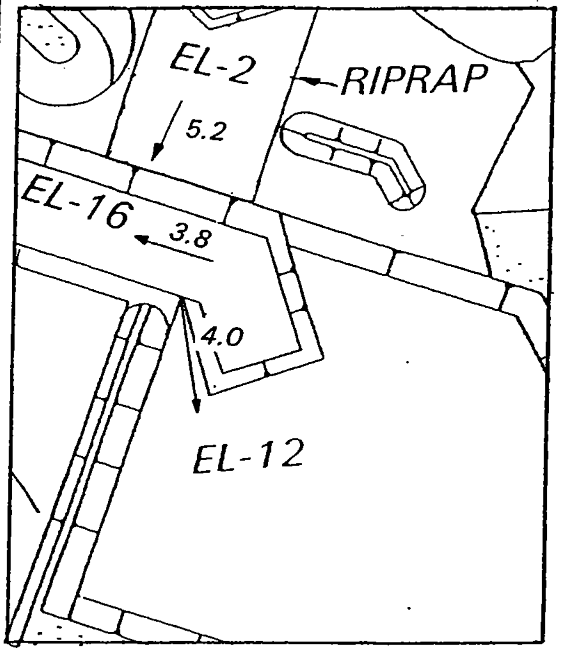
Wave induced current patterns and magnitudes (prototype feet per second) obtained for Plans 33-35, 16-sec, 19-ft waves with the +3.2 ft swl



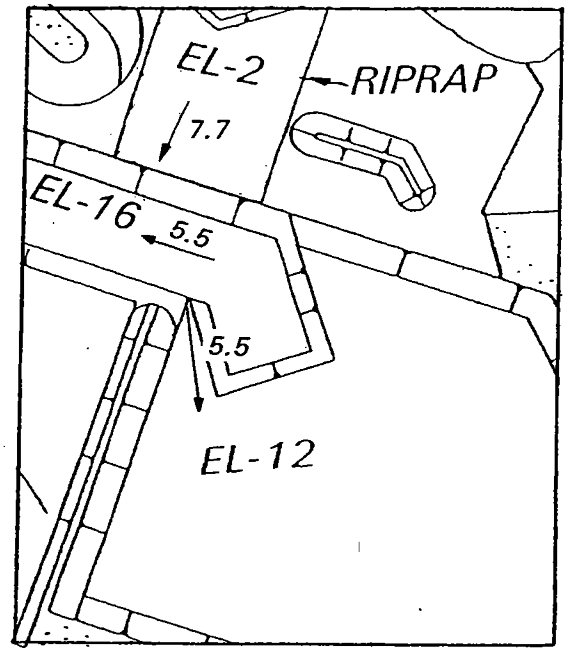
Ebb tidal currents for Plans 35 and 36 for the +7.0-ft tide range



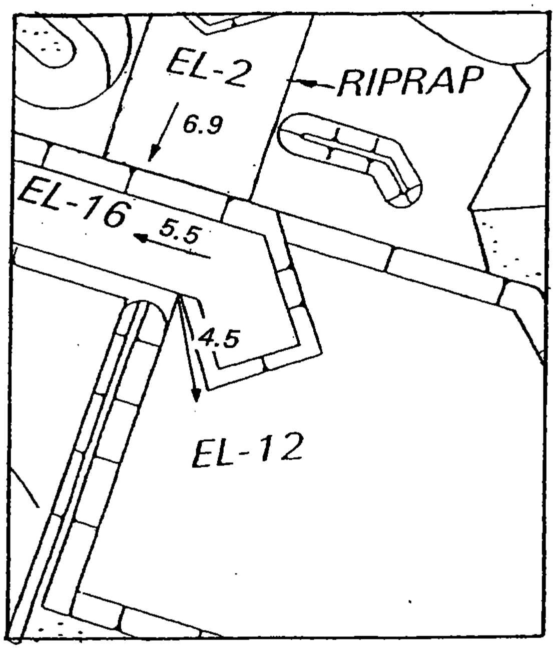
Ebb tidal currents for Plan 37 with and without waves for the +7.0-ft tidal range



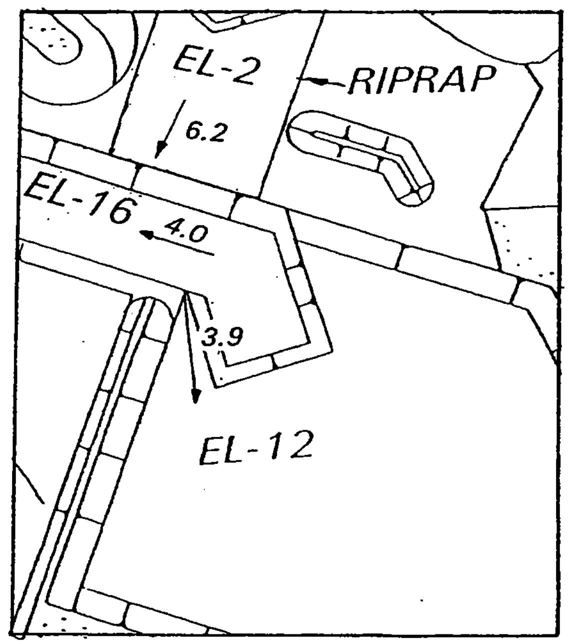
10-sec, 10-ft waves



16-sec, 19-ft waves

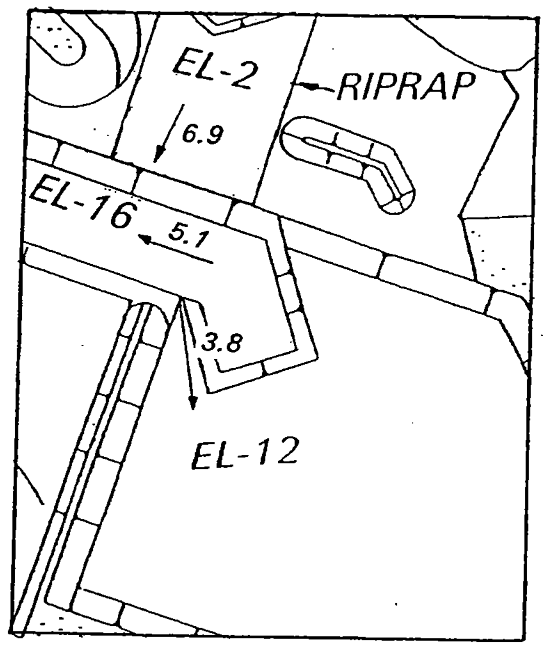


20-sec, 14-ft waves

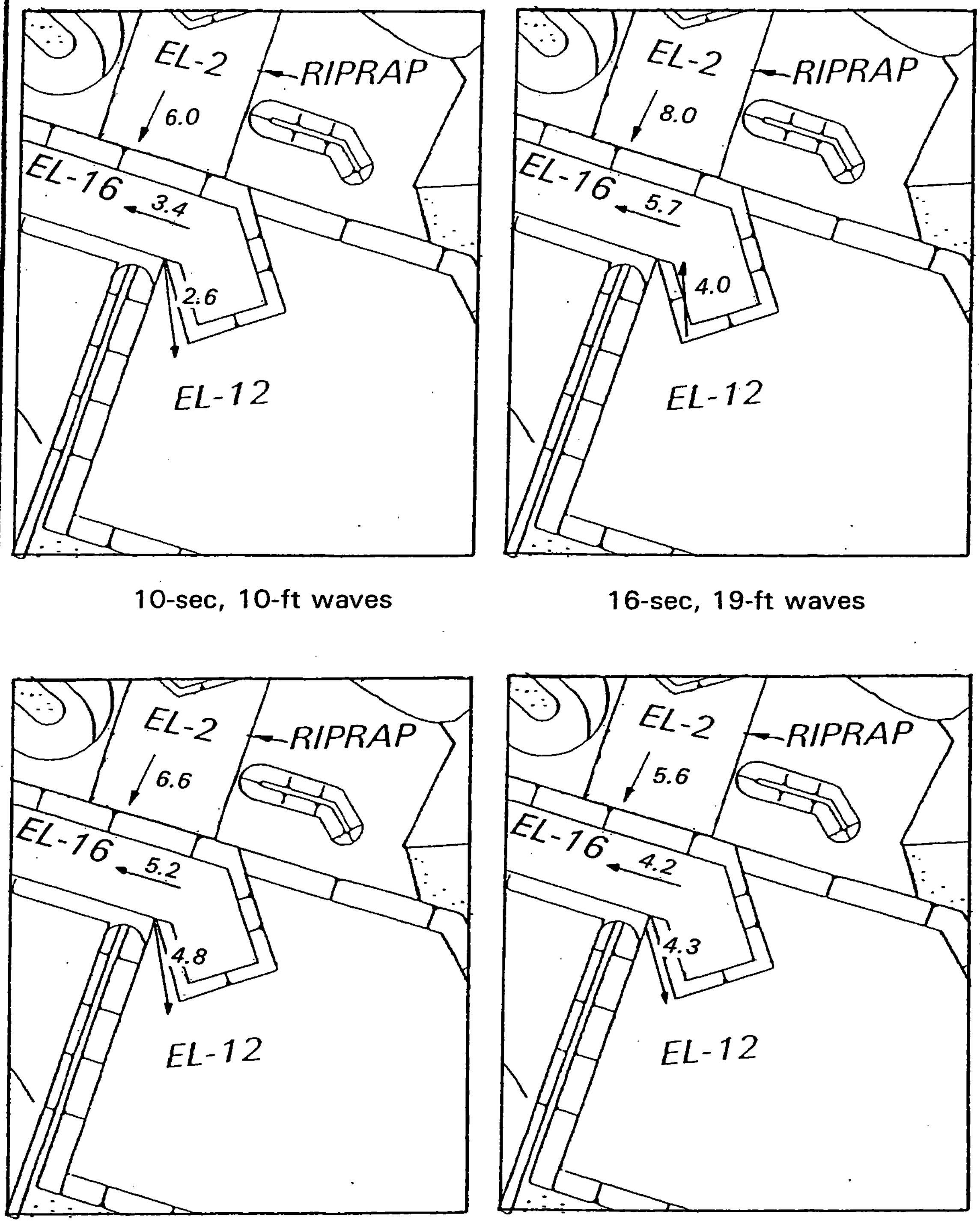


25-sec, 10-ft waves

Wave induced current patterns and magnitudes (prototype feet per second) for Plan 37, swl= +3.2 ft



Wave induced current patterns and magnitudes (prototype feet per second) for Plan 37, 16-sec, 19-ft waves, swl = +7.0 ft



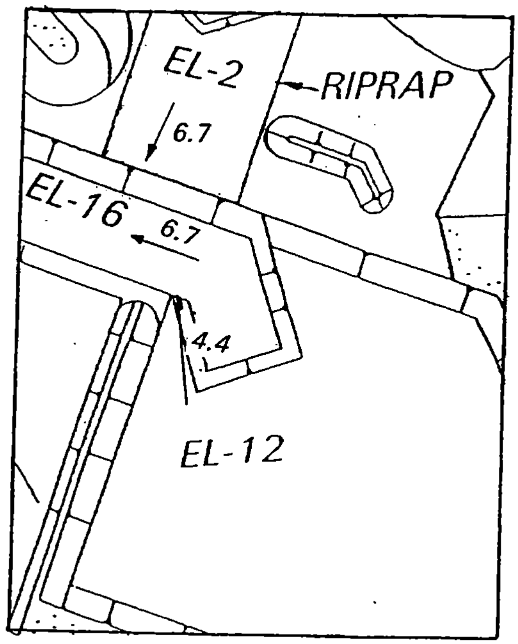
10-sec, 10-ft waves

16-sec, 19-ft waves

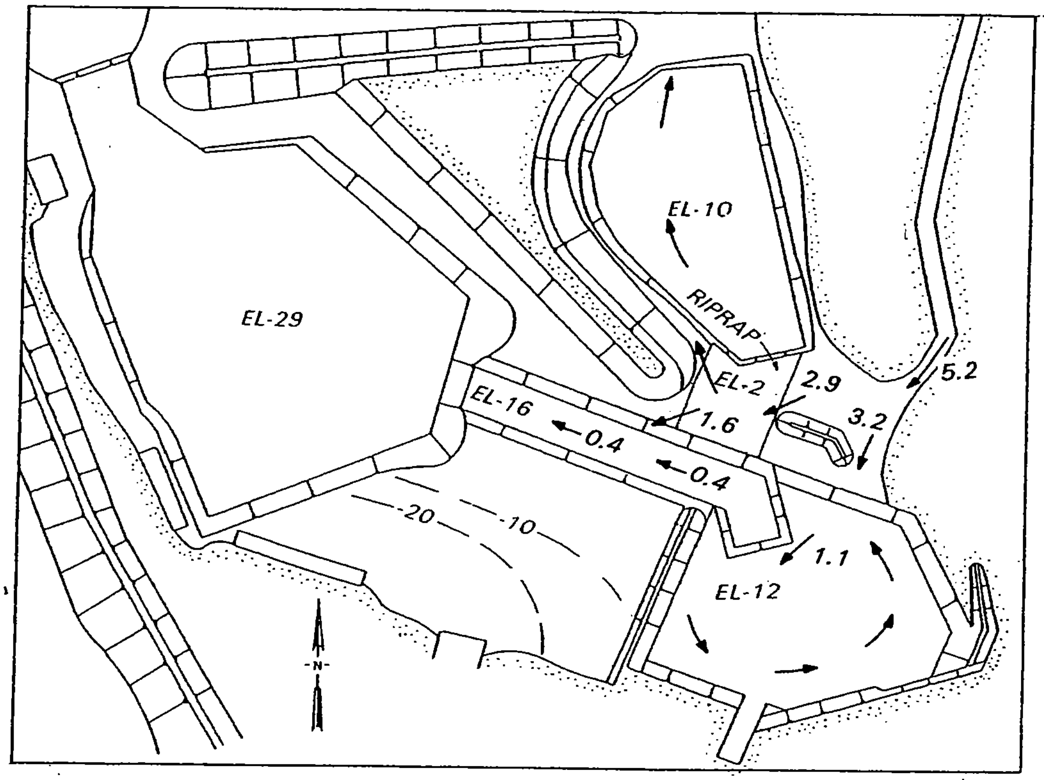
20-sec, 14-ft waves

25-sec, 10-ft waves

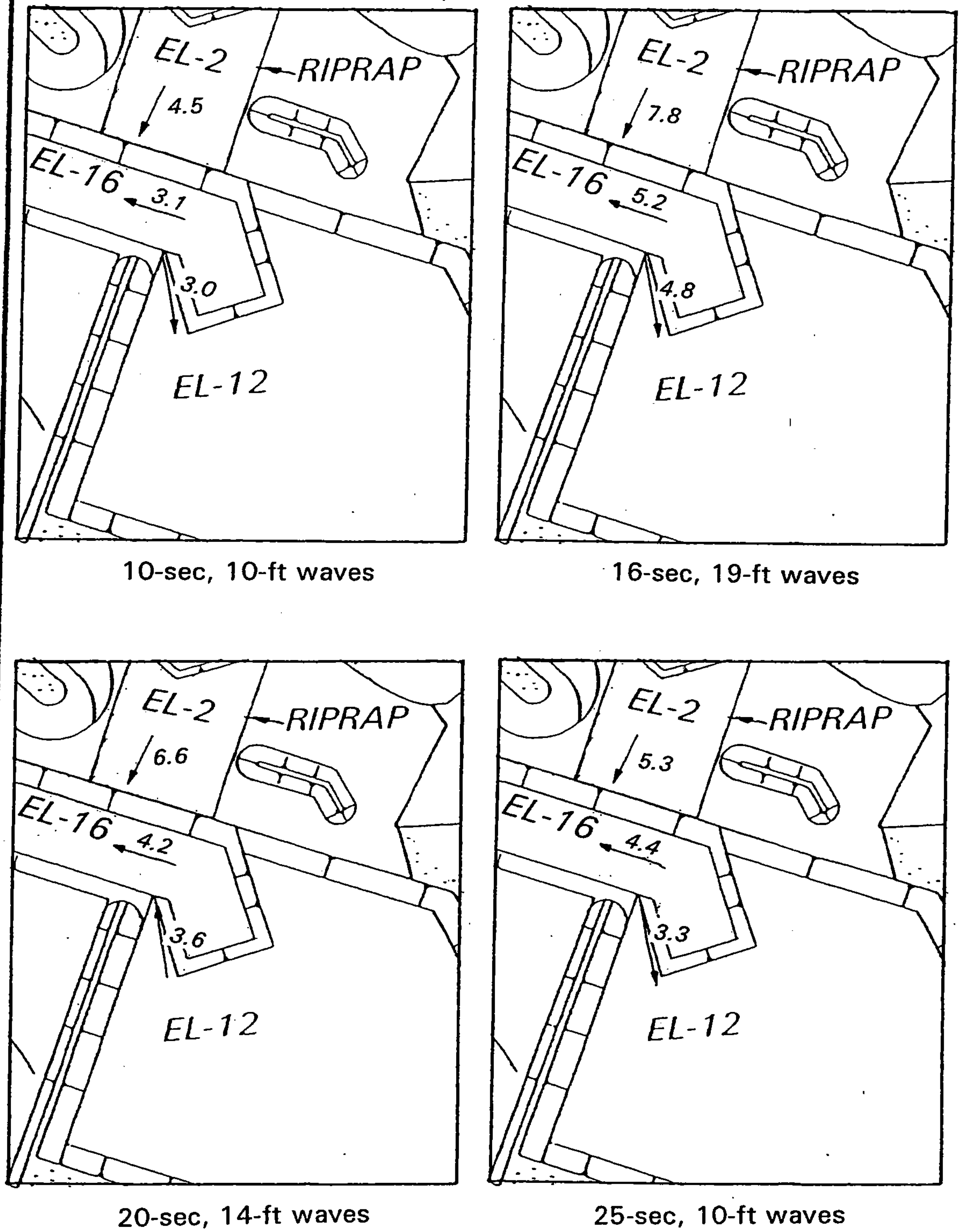
Wave induced current patterns and magnitudes (prototype feet per second) for Plan 38, swl = +3.2 ft



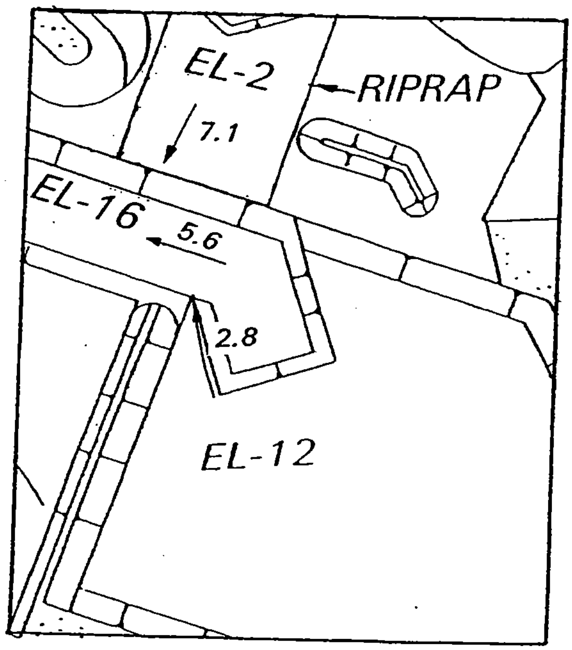
Wave induced current patterns and magnitudes (prototype feet per second) for Plan 38, 16-sec, 19-ft waves, swl= +7.0 ft



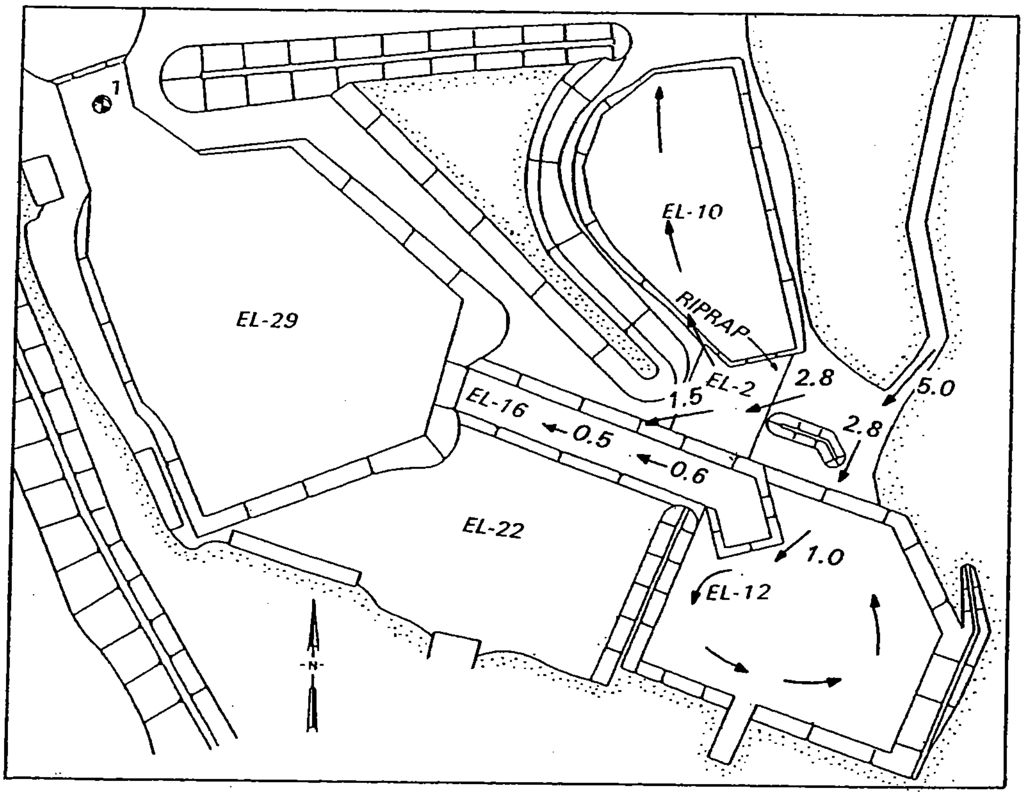
Ebb tidal currents for Plan 38 for the +7.0-ft tide range



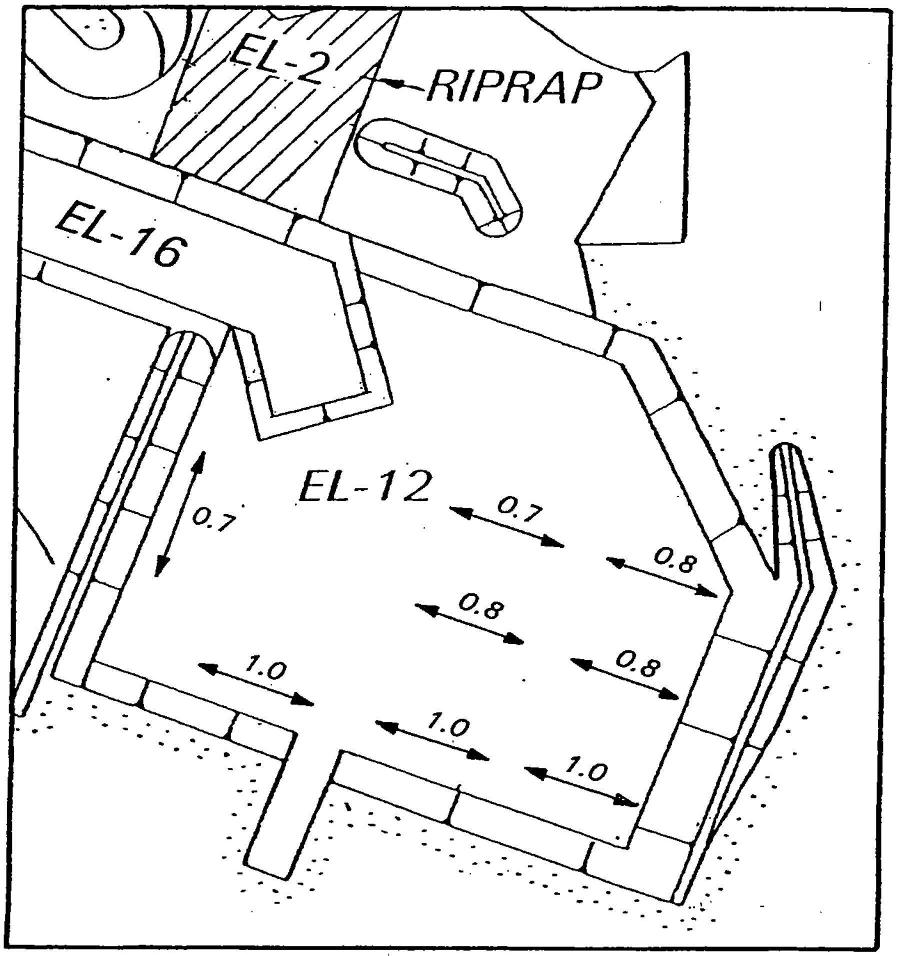
Wave induced current patterns and magnitudes (prototype feet per second) for Plan 39, swl = +3.2 ft



Wave induced current patterns and magnitudes (prototype feet per second) for Plan 39, 16-sec, 19-ft waves, swl = +7.0 ft



Ebb tidal currents for Plan 39 for the +7.0-ft tidal range



Current directions and maximun velocities (prototype feet per second) associated with harbor seiche for 60-vessel configuration

A-3.3.1

February 2001 Draft Report

Design for Small-Boat Harbor Improvements and Tidal Flushing at St. Paul Harbor, St. Paul Island, Alaska; Coastal Model Investigation

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Coastal and Hydraulics Laboratory
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Miscellaneous Paper
ERDC/CHL-01-

USAE District, Alaska
Post Office Box 898
Anchorage, Alaska 99506-0898

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

A 1:100-scale (undistorted) three-dimensional coastal hydraulic model was initially used to investigate the design of proposed harbor improvements at St. Paul Harbor, St. Paul Island, Alaska, with respect to wave and current conditions in the harbor and sediment patterns at the site. Wave-induced circulation and sediment patterns seaward of the main breakwater as a result of submerged reefs were investigated. Proposed improvements consisted of deepening the entrance channel, constructing a maneuvering area and installing a wave dissipating landfill inside the existing harbor, and constructing submerged reefs seaward of the main breakwater. The model was reactivated in 1997 to study, on a preliminary basis, small-boat harbor improvements and flushing of Salt Lagoon in St. Paul Harbor. In this study, the model was reactivated to finalize the design of small-boat harbor improvements and flushing at St. Paul Harbor. The model reproduced approximately 2,865 m (9,400 ft) ft of the St. Paul shoreline, the existing

Tidal flushing
Harbors
Wave protection
Hydraulic models
Wave-induced currents
St. Paul Harbor, St. Paul Island, Alaska
Wave dissipating landfill

UNCLASSIFIED UNCLASSIFIED

19. ABSTRACT (Continued).

harbor, the surface area of Salt Lagoon with its connecting channel to the harbor, and sufficient offshore area in the Bering Sea to permit generation of the required test waves. An 18.3-m-long (60-ft-long) unidirectional, spectral wave generator and an automated data acquisition and control system were used in model operation. It was concluded from study results that:

a. Preliminary experiments indicated that all improvement plans would result in wave heights of less than 0.3 m (1.0-ft) in the small-boat mooring area for short-period storm wave conditions.

b. Preliminary experiments indicated that the harbor would experience long-period (surge) conditions for all the improvement plans.

c. Preliminary experiments indicated that the area between the wave-dissipating spending beach and the interior detached breakwater should be constructed to an el of -0.6 m (-2.0 ft) to reduce wave heights in the small-boat harbor mooring areas. Excessive wave-induced currents in this area, however, indicated that the area should be hardened (capped with riprap) to prevent scour.

d. Preliminary experiments indicated that strong wave-induced currents in the interior channel may cause navigation difficulities for extreme storm wave events. Strong wave-induced currents along the area east of the shore-connected breakwater also may pose problems for vessels mooring in this vicinity. These current magnitudes also indicate that toe protection at the head of the structure may be required.

e. Preliminary experiments indicated that the angled interior detached breakwater would result in enhanced circulation and better distribution of flow in the small-boat harbor basin for ebb tidal currents as opposed to the straight structure.

f. Preliminary experiments indicated that the -4.9-m-deep (-16-ft-deep) interior channel would result in enhanced wave-induced circulation and stronger eddies in the small-boat basin as opposed to the -3.7-m-deep (-12-ft-deep) channel.

g. Experiments indicated that the 60-vessel plan configuration (Plan 37) will provide adequate wave and surge protection to the small-boat harbor as well as adequate harbor circulation.

h. Experiments indicated that the 30-vessel plan configuration (Plan 38) will provide adequate wave and surge protection to the small-boat harbor as well as adequate harbor circulation.

i. Experiments indicated that a reduction of depths in the harbor to -6.7 m (-22 ft) west of the interior shore-connected breakwater (Plan 39) will have no negative impacts on wave and surge conditions or harbor circulation in the small-boat harbor.

j. Experiments indicated that long-period surge conditions in the harbor should not cause problems in the small-boat mooring areas provided dock systems are properly oriented and vessels properly moored.

k. Experiments indicated that the 0.0-m (0.0-ft) el of the wave-dissipating spending beach (with the +1.2-m (+4.0-ft) berm along its perimeter) studied during this period will provide essentially the same level of protection from storm waves in the mooring area as the +3.7-m (+12.0-ft) el spending beach tested in earlier studies.